No. 30

SOME OBSERVATIONS ON THE TEACHING OF DESIGN

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DEPARTMENT OF MECHANICAL ENGINEERING

TECHNICAL REPORT

No. 30

"Some Observations on the Teaching of Engineering Design"

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1. INTRODUCTION

Mechanical Engineering Design 3 - the final year course as presently existing in the Department - represents a developed state of that which obtained some years ago. The writer undertook to try to bring into the coursework studies which would exercise engineering interests and imagination as well as appeal to the social service aspects of the profession. Also he considered it important that a major design study should embrace an attempt to design a complete piece of plant, or a system, in detail, and that in so doing at least some topical contact with industry might be contrived. This was not always as successful as could be wished!

Further development of the coursework ought to emphasise the intellectual skills of the Design discipline - but, to do this needs a body of knowledge presently beyond the writer's capability. The course has reached a 'bar', progress beyond which requires a minor revolution of philosophy as well as content.

There are indications that similar changes have been proposed and are in the process of implementation overseas. (These and other references: Wilde, 1981, Crouch, 1981, Wallace, 1981, Lamming, 1981, "Engineering Design Education", Inst. Chem. Engs., "Current Design Thinking", 1979).

Within the provisions of undergraduate curriculum and of time - so much seems indispensible, yet so much more becomes desirable.

There are, possibly, three ways of development waiting to be explored:

1. A fourth professional year, of "Engineering Practice', jointly with industry and 'Industrial Professors'. Emphasising, Marketing - Design and Management, studies.
2. Postgraduate, post experience courses in Engineering Practice - especially design centred, once again utilising 'Industrial Professors'.
3. Research into the Intellectual Process of Design so that a fundamental

and scholarly foundation of knowledge of the structure of the discipline may be demonstrated, upon which teaching can proceed.

Towards these ends the writer dedicates these observations.

2. DESIGN IS NOT A SUBJECT

Within the curriculum of Engineering studies at University (and Polytechnic) teaching tasks are customarily packaged in subjects; such as, Physics, Chemistry, Mechanics, Thermodynamics and so on. Each subject is treated as a discipline, complete in itself, (almost watertight), investigating and explaining natural phenomena through the medium of analysis and experiment applied to classical model situations.

Design cannot properly be treated in this manner. The principal reason for this is that Design is an activity. To design is to set forth actually to do something in order to fulfil a need. The process is seen to be made up of a personal human content as well as the application of knowledge and technique. The manner of the designing depends upon the personality of the designer - his 'style' - so that Design is a socio-technical activity.

The objective of Engineering Design activity is the provision of a prescription for a thing to be made, usually as a set of instructions, enabling the means to fulfil the need, to be constructed successfully. So that the Performance meets the Specification, and the Endurance and Maintenance are economically acceptable. This requires mutli-discipline based and exceptionally well organised activity, by groups of skilled persons.

3. MOTIVATION MORE THAN KNOWLEDGE

The act of setting forth to undertake a design task implies movitation and persistence, but not necessarily, to begin with, an extensive and deep knowledge. Primarily a strong desire born of dissatisfaction with the current state of the art which fuels the urge to do something constructive.

This is most apparent in the observed and reported behaviour of inventors and senior creative designers, (Rossman, 1964, Nervi, 1956, Whittle, 1945, and many more).

Nevertheless, the motivation must exist and be shared between senior and junior people making up design teams in industry. Otherwise the recurring difficulties of engineering design work of any technical depth become insupportable. (Booker, 1962, Marples, 1961, Rossman, 1964, etc.).

4. INDIVIDUALITY OF DESIGN ACTIVITY

The personality of every person who designs affects the interpretation of the needs, the choices considered, the decisions taken and the progress and outcome of the design work. The individual designer probably initiates the background research and development programme, he monitors its progress and governs its extent.

The manner by which each designer utilises the knowledge he develops and the techniques of the design process is a function of his beliefs and feelings, his "style", and cannot be dictated in, say, a series of 'How to do it' lectures. (Bulleid, 1977, Smiles, 1904, Nervi, 1956, etc.).

Teaching Design then may require a systematic programme aimed to influence personality rather than a recital of process techniques alone.

5. LIMITATIONS OF LECTURES

Lectures may outline the suggested content of the Design Process, viewed as a set of activities, and provide reference information about the necessary background knowledge, and techniques of design practice. (See Supplementary Coursework Notes, Appendix 1).

The conventional lecture format is a passive situation for the student, who becomes a note taking automaton consigning the content of the lecture to limbo until some constraint compels him to resurrect it. Over the years the lecture timetable has steadily expanded to occupy virtually all the available hours, even to early afternoon periods.

Design sessions are best separated from lecture periods by at least an overnight rest.

6. AN INTELLECTUAL DISCIPLINE

Since Design is not fairly treatable as a subject, then how should it be treated? To answer this one needs a valid model of the Design Process itself, not the Practices as presently evident.

Design is an intellectual discipline, practised by persons motivated to achieve the objective of providing a means to fulfil a need.

It becomes apparent to any other person interested in the art as a constructive and organised activity, diligently pursued by inventors and designers (e.g. Christopher Hook, Frank Whittle, Bill Hamilton, Henry Royce, etc.).

Some aspects of the discipline that have been described, in isolation, are - Perception, Visualisation, Imaging, Creation, Prediction and Judgment. The discipline of Design enjoys only indirect and fragmented description by consideration of these aspects, and through the medium of the techniques of Design practice. These are treated as subjects (although not all in the School of Engineering), but not as indispensible parts of a complete systems model of the intellectual process. This remains therefore relatively undefined.

7. PURPOSEFUL BEHAVIOUR

Case studies of engineering design show common characteristics. Progress is made through the recognition of, and the eventual resolution of, a series of choice situations which arise as the work proceeds.

This resolution is marked by the taking of a decision at each choice situation (e.g. Smythe in Rossman, Whittle, Booker, Marples, etc.).

Such behaviour on the part of the designer and his team is typically purposeful. Defining objectives and working through all social and technical difficulties to their achievement.

8. ENCOURAGE STUDENTS?

In trying to 'teach' design the central problem encountered by the tutor is how to encourage students to think like, and behave like, designers?

For the majority, this will be their first encounter with the discipline of thinking to some purpose, and it will make design work so much more unfamiliar and difficult for them.

The common tendency is for the student to postpone his design study as long as he can, concentrating upon that work which is more familiar to him - problems in the engineering science subjects, and laboratory work of the kind reminiscent of high school.

A designer's impetus comes from his own motivation - design cannot be thrust upon anyone.

9. SIMULATION OF THE DESIGN SCENARIO

It becomes necessary to introduce students into a situation requiring them to behave as designers. A considerable incentive to this is the prospect of undertaking a study which happens to fall within the field of interest of the student. This engenders motivation, holding out the prospect of developing a special kind of knowledge, increasing status, and earning coursework merit by actually 'doing Engineering'.

To achieve this the tutor needs to simulate, in an academic environment, as close a model of a professional design environment as possible. Some considerations to this end are:

10. A PLACE OF WORK. Each student should have a desk of his own - one capable of storing a reasonable number of reference books and files of source material, also a small drawing board and storage for instruments and a

calculator. Access to a larger draughting system should be available as and when required.

11. RECOGNISED RESOURCES.

Library access, with skilled guidance to more remote collections. This should include or be supplemented by a library of manufacturers literature kept up to date at regular intervals.

Secretarial services tailored to suit the design teams or individual designers requirements - printing and reproduction of reports, and drawings.

The Design Office should enable design teams to hold uninterrupted seminars, and make special provision for display of sketches, drawings, interactive work on large chalk boards as well as computer video displays. A model display area is a worthwhile addition.

12. PART OF A TEAM

It is probable that some students will prefer to work as individuals - however, most would probably feel happier to be a member of a design team. Discussion and consultation lend technical assistance and psychological help especially to those whose talent for design may be latent or small.

The smallest effective design team is three individuals, comprising the design engineer (the tutor or industrial professor), a design draughtsman (technician staff employee of special experience in design work) and the student designer (or possibly 2 or 3 students).

13. A DESIGN BRIEF OF INTEREST

The intrinsic appeal of the proposed design study is very important. Case histories of creative work, including engineering design, always show the critical value of motivation (Whittle, etc.).

To match every student to a study that meets his enthusiasm for a particular aspect of engineering is unlikely to be achieved. However, a reasonable range of topics can usually be presented. See for example

Technical Report No. 16 and Appendices below.

It may be argued that, in industry, in later life such freedom of choice would not obtain. But to have experienced it once at a critical stage in his career may provide a lasting impression, stimulating and confirming a young engineer as an embryo designer of some talent - otherwise lost.

14. A DESIGN PROGRAMME

Once chosen, commitment to the design study is best monitored by means of a work programme, which requires regular attendance at seminars, at least during the initial stages of the work.

Display of the schedules in the Design Office, with regular revisions as the work proceeds, is probably worthwhile. The finishing date should form part of the initial design brief, and be emphasised during each review of the progress made. However remote the objective of the study may be, encouragement on the way can be arranged by defining progressive goals which are demonstrably attainable to schedule.

15. THE ROLE OF LECTURES DURING A DESIGN COURSE

1. To draw attention to immediately relevant background knowledge.

2. To outline the state of development of systems of synthesis and analysis relevant to the design process.

3. To describe and illustrate techniques of value to the designer.

See Appendix 1 'Supplementary Course Notes' and Appendix 2 'Syllabus of Design 3'.

16. SEMINARS

1. Using case history material to illustrate and study the practice of Design, and the variety of Design, by individuals and by organisations. This may be written case studies or the personal presentations by visiting designers, or industrial professors.

2. Progress monitoring. This is the difficult task. Care is needed to try to encourage the student designer to take responsibility for <u>his</u> own design, through the taking of a series of informed decisions by himself, <u>not</u> by the tutor. Information and/or its sources may be given but advice on specific issues is withheld, unless such a state of distress is seen to exist that it is obviously essential, to any progress whatsoever.

Carefully considered questions should be posed to try to enable the student to think his design problems through. Application of techniques dealt with in lectures, where possible, should be encouraged.

However, it is the experience of the writer that:

1. Student groups of not more than 4 persons per design study function best at seminars.

2. No matter how carefully seminars are scheduled, and study progress plans are recommended, students will follow their own inclinations in these matters!

17. SOME TECHNIQUES OF DESIGN PRACTICE.

Every Design Office has a routine peculiar to its staff and the engineering design field in which it specialises. Development of its practice with the introduction of new techniques and technology probably depends upon the vision of its chief executive as much as the availability of capital, and its status with the company board.

At undergraduate level the design course should include a survey of techniques, as mentioned above, and where possible some exercise in those relevant to the studies in progress. Case histories too should be chosen to illustrate them.

At postgraduate/post experience levels with the enhanced chance of industrial co-operation then the study of design practice techniques can form a major part of the coursework content.

For example:

1. Creative Thinking. Methods of individual and group attacks upon a problem situation using 'brainstorm' and similar techniques can be applied directly to many creative design studies. See Technical Report No. 16.

2. Systematic Method. "Disciplined Creativity" (Bailey 1978). Interactive use of analytical studies of a design situation, with progressive conceptual changes of viewpoint (Matchett 1963-19670). Directs attention and increases attention span.

3. Project Planning. When a thorough grasp of the probable extent of the work, and the activities and events involved, is gained. 'Critical Path Method' recommended.

4. Optimisation. Applied to specific cases of interactive analysis for machine component and assembly design. Can show a way to marshall the evidence for a range of alternatives so that an informed choice of the optimum for the time being becomes possible. (Johnson 1961, Siddall 1972).

5. Decision Taking. Utility and Value Judgements. Prediction of performance for each alternative, and comparison to an ideal. Ranking of alternatives by value rating.

6. Presentation. Methods of summarising and displaying design activities in chart, or tree of decisionswith consequential sub-problems and solutions.

Design portfolios. Reports and Drawings. Use of models to explain technical constructions to lay persons (Appendix 2).

18. TOWARDS A NEW MODEL OF DESIGN.

As a 'set of activities' the model of the Design Process excludes the designer(s). Exercise in the techniques of Design practice alone does not necessarily influence the beliefs and feelings of a designer, does not change his personality - although his knowledge and understanding of the analysis of design situations should improve.

Little in the lecture or seminar material may attempt directly to teach the design discipline. Indirectly through the medium of creative work, interactive visualisation, and optimisation exercises, the designer does exercise himself in aspects of the discipline.

This may be interpreted as behaving in a purposeful way and it seems reasonable to try to create a new model of the Design Process as a purposeful system. A more rigorous answer to the question of 'How does a Designer Design' may be formed. Such a model may take account of the Designer as a psychological individual acting with a will and possessing personality. It may also be a valid model for the Design team as a social group working purposefully towards successful completion of a project. (Ackoff and Emery).

It should provide a better definition of the Design Process - we shall then know when a person or a social group is designing. We may better predict how many persons and what skills we need in a design team. We shall know what kind of environment to provide. The education of designers should then rest upon a better foundation, since the concept of Design as a discipline, will be given a more comprehensive structure.

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Appendices

1. "Engineering Design - The Constructive Art". Notes Supplementary to the Coursework of Engineering Design 3 (Mech.).
2. Syllabus, Design Studies and Presentation Note for Engineering Design 3 (Mech.).

APPENDIX I

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN - THE CONSTRUCTIVE ART

C.A. Satterthwaite 1984

INTRODUCTION.

I. The origins of the design discipline.

II. The Design Process.

III. Knowledge and Creativity

IV. Optimisation.

V. The Design Function in Industry.

VI. The Designer?

INTRODUCTION

The purpose of these notes is to provide a reference survey of the art and process of engineering design with a guide to the literature that seems most useful to the student designer at the present time. It is a personal selection and point of view.

Design may be studied as an intellectual discipline in its own right. However, it is probably more rewarding to recognise design as an organisation function, a feature of the management system, and to embody philosophical and some psychological aspects of the designer's expertise within the study. Later special and more academic aspects of the structure of the design process itself may be emphasised.

Engineering design has often been interpreted narrowly (for example) in terms of 'Stressing' of structures and machine elements, i.e. as a purely technical expertise.

A more comprehensive appreciation of the power and value of engineering design will be developed, it is hoped, built upon the following definitions:

Engineering. Is purposeful, practical, ingenuity employed in the service of mankind.

Design. A process of creation, eventually to generate a message which prescribes completely and unambiguously what is to be done to fulfil a need.

Engineering Design. The application of the design process in the field of engineering. It features as an organisation function, enabling management policies to be realised as products, and is crucial to the continuing vitality of any manufacturing company.

Design Practice. Has been described as the 'art of engineering' and a 'central theme' (CORFIELD 1982) because:

1. The practice of design makes use of other disciplines to achieve objectives, e.g. it uses Sciences, Technologies, Manual Skills, Social Organisations, and Professional Expertise from many other sources. Over and above this it generates the incentive to develop further knowledge and skills in the relevant fields.

2. Also, because of the power and leverage of Design practice to influence

the quality of life. Power to provide tools to improve as well as to threaten life. Power to provide answers to calls for help, to relieve drudgery and to obtain and retain richness and variety of life.

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I. THE ORIGINS OF THE DESIGN DISCIPLINE

The original, and fundamental, incentive to undertake any form of contemplated, or actual, constructive activity is to be found in the perception of a need.

In the beginning the necessity for man to survive in his environment motivated him to the development of a set of activities which ensured that, with the aid of tools relatively easily found, food, clothing and shelter were provided.

This represents engineering at a basic level - the application of ingenuity to the solving of a problem and the provision of a service to mankind.

Not every person has the talent or inclination to recognise a need. In this field as in all others there are leaders and there are followers. Those who do exercise such a talent have a special aptitude for observation and for relating what they perceive in the environment, and what they remember, to human conditions and to resources so that opportunities become apparent. A form of 'Divine Discontent' motivates them in a continual search for improved ways. (Rossman 1964).

Recognition of a need is prompted by physical conditions, hence the incentive to do something to relieve discomfort, avoid drudgery and danger, and preferably, provide a thing or system which shall endure and enable a better way of life to obtain.

Enabling systems - from the simple tool made from material resources literally 'to hand', to complex machine systems and organisations made from diverse resources, gathered over time and distance.

These systems can:

(a) Increase the material standard of life, directly, by the provision of machines and structures.

(b) Increase the cultural quality of life, indirectly, by making possible leisure time for recreation and study, i.e. increase the real 'wealth' of a society.

Enduring systems - the quality of the instruments devised and utilised becomes important since effort (labour and time) is invested and an 'economic' life even for the simplest tool, is expected by the user (or consumer). Hence such products of human ingenuity are valued.

It is the need, once perceived and defined, that 'pulls' and not the level of knowledge of the principles of natural phenomena that 'pushes' in the majority of cases of invention (Smookler 1966). Science in the form of the pursuit of knowledge for its own sake does not automatically foster invention. However, once a decision is taken to attempt to find and to construct a means to fulfil a need, then the value of relevant knowledge, and the need to know more, becomes apparent. Hence 'Industrial and academic research'.

"Necessity is the mother of invention".

The incentive to do something, taken up as a challenge to the ingenuity of man, and persevered with to a successful conclusion is the discipline, and the set of activities used is recognisably a first description of the Design Process which we study.

In the most basic form of society the provision of food, clothing and shelter still generates the needs, and they are real and urgent. In the developed forms of society (often called 'Western') fundamental needs have been satisfied for a long time and this is taken for granted. More sophisticated classes of need are apparent, generated by the enhanced standards of living and by cultural pursuits based upon the desire for a variety of accomplishments, the satisfaction of curiosity, and the exercise of imagination, e.g. to be mobile, to be comfortable, to search for truth, to appreciate and to generate beauty, to experience physical and intellectual achievements, perhaps in short to achieve self-fulfilment.

In such a complex developed society, not all needs are real in the sense they are essential for survival nor yet can many such needs be said to be urgent. Nevertheless they exist and serve to provide origins for a great deal of design activity.

<u>The rise of the Specialists</u>. With the passage of time the exercise of human ingenuity passed along and developed from generation to generation, has resulted in an increasing body of practical knowledge of a variety of arts. These are embodied in a number of trades, crafts and professions, which individuals of relevant talent exercise for a livelihood. The result is more and better resources available in the form of 'technology' - a

TURN OVER

principal enabling resource to the designer to provide, in turn, better instruments to satisfy needs.

The possibility which existed initially that one person alone would recognise a need, and that the available resources could be made to provide a tool to satisfy it and, furthermore, that he could himself design, construct and use the tool, is not now often the case.

When the functions of design, construction and use were commonly executed by the same individual, he would be closely associated with the artefact and its environment over his lifetime. As a user, such intimate contact with materials and tools meant there was no conscious realisation of separate specific acts of creation and development. The perception of any problems and the possibility of improvements arose out of the demands of customary usage and did not require explicit definition verbally or visually (as specifications or drawings): one simply operated upon the artefact itself and referred it immediately to its environment.

Design, in these circumstances, could be described as an exercise in the evolution of a form better fitted to operate in its environment; an unselfconscious activity. (Alexander 1964).

Perception the initial mechanism of the evolutionary activity remains a fundamental intellectual ability for all designers.

A significant change began to occur in the relationships between creation, construction and application.

The skills of construction soon became the special talent of tradesmen. Skills of creation, organisation and accounting also became the province of specialist professionals.

With the recognition of the increasing resources of materials and skills, so entrepreneurs and those of design talent became the originators of social groups, organised to develop and to manufacture more or less complex machine systems for society.

No constructed thing is perfect so that there is a continuing incentive springing from consumer dissatisfaction to develop and to provide better, more economical, performance.

The entrepreneur who matches a perceived or created need to the resources available exercises the initial action of the set of activities we may call the 'Design Process' but he is seldom also the designer. (However, see Jewkes, 1969 and Whittle, 1945).

The pace and the complexity of construction increased sharply with the Industrial Revolution in England. Previous to that radical departure, established trades (crafts) provided well known and appreciated tools to enable a settled and well understood way of life to continue. Change was a matter of small increments only accepted after extensive experience. Resources were regarded as inexhaustible. Articles of use were constructed by routine craft systems regarded as the only correct method. The environment was invariable. Only a few gifted individuals sought to question or to try to verify, scientifically, methods of construction, design, and the resources used; tried to understand with a view to improvement. (Sturt 1942, Hill, Jones 1970). Fundamental inventions, products of the design discipline, physical embodiments of natural principles, have become the stock of machine elements we now utilise as resource material in later designs. Each is basically simple and each is therefore the indispensable prior requirement to the development of a technical creation (Leyer 1974).

As certain thoughtful persons reviewed their practical working experience, and developed their background knowledge, so they perceived and described the problems to be solved if any developments in performance, methods, or products were to take place. Predominantly interests focussed on the relief from arduous manual toil and by working towards their vision, when the time became opportune, so the Industrial Revolution occurred, e.g. colliery tramways towards a railways system. From Newcomen to Watt and to the industrial steam engine, and so on.

It was an explosion in the application of energy. Power to develop and exploit, materials, knowledge and mankind. Mechanical engineering as a profession came into existence. The growth of the economy followed the growth of technology (Smookler 1966, Martin 1973).

The more complex the machine system, the more complex the organisation for its manufacture, and the greater the degree of specialisation by the individual persons working within the organisation. The 'set of activities' has now been removed from the actual place of construction and features as the province of a team of professionals devoted to design as a function of the organisation. The Design Process has become a more or less systematised professional engineering activity, and as such we shall study it.

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II. THE DESIGN PROCESS

What form may that 'set of activities' take? In considering the development of the design process from early origins we necessarily take an empirical stance. We study what has taken place through reports, and the evidence provided by case histories and the surviving artefacts.

The resulting picture, generalised and to some extent, idealised, is of a process of yesterday and today but not necessarily that desired for tomorrow!

In considering the lessons to be learnt and the developed form for the future we should notice these significant changes.

1. The problems to be solved during design development work have become, and are still becoming, much more complex and difficult to handle, than those of primitive mankind. (Jones 1970, Alexander 1964, Wilde 1979).

2. In the transition from the unselfconscious process, immersed in its context, to the detached professional self-conscious design activity, the use of drawings has proved to be one of the most powerful tools. This rigorous visual aid has increased the designer's immediate attention span, provided a recording and a recall system, and an interactive form developing instrument so far unsurpassed in value. (Booker 1963, Baynor and Pugh 1981).

3. The recent revolution in the power of computing made available by the development of electronic computers has, happily, provided a means to tackle problems of calculation previously regarded as intractable. It has also put at the designer's disposal access to much more information, at very short notice. As an interactive form design tool the computer may offer visual aid facilities presently under development that supplement the traditional drawing (Wilde 1979).

4. The professional design team engaged in the creation of products having a highly technical content has become an organisation including and consulting many Specialists, technologists and scientists. This has resulted in a tendency to overlook the leading role of the designer, and consequently his status has generally suffered. (Wilde 1979).

The empirical description of the design process is constructed by enumerating the successive acts observed in practice from the recognition of the particular need to the eventual specification of the hardware to fulfill it. This constitutes a morphology of the set of activities as it has developed, and can be seen in operation in a variety of manufacturing industry.

Each act in the set has become the object of study and description as a methodology or technique, by a variety of authors (such as Wallace 1952, Asimow 1962, Ostrofsky 1977, Bailey 1979).

Whether we study the process as the behaviour of an individual designer or - as is more common - that of a design team, we are now dealing with a selfconscious activity in the sense Alexander describes.

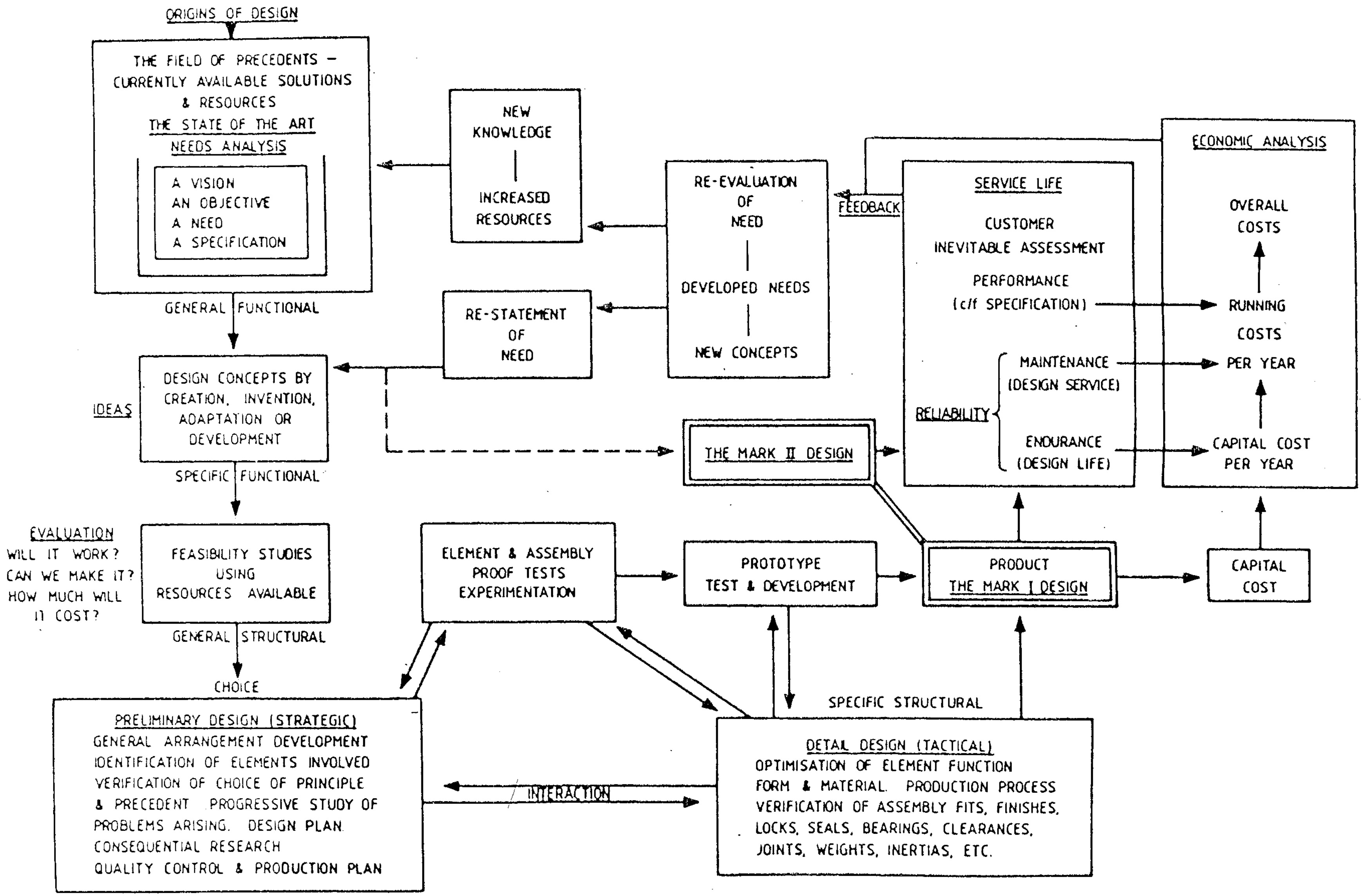
Design by evolution may be initiated by an individual's discontent with the performance of an existing tool, which inspires the curiosity to see if something can be done to remedy the defect. This if successful may provide motivation to pursue the design development into the professional set of activities of an organisation (Wilson 1975).

Consideration of the isolation of the set of activities as self-conscious design, physically separated from the materials of construction and the environment of use, soon leads to the realisation of the significant role played by the designer's perception. His ability to manipulate his experience and knowledge, to visualise mental images, to predict consequences and to optimise systems, we shall see as all-important.

A Model

The diagram shown here emphasises the overall picture and has been disposed to show the iterative nature of the process. We progress from top left through the various stages in an anti-clockwise sequence, which may be repeated as is indicated, as often as the product in question undergoes design-development to a further Mark No. We accept the design task and proceed from concepts to images from abstractions to eventual hardware, passing through stages which have become generally accepted as characteristic of engineering design, in fact.

This diagram is not unique, other writers have published their own versions, notably Asimow , 1962. He has provided separate and more detailed flow charts for the stages of the process, feasibility study, preliminary and



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detail design. Marples 1960, has described design as a progressive decision taking process, and Booker 1962 has also illustrated this aspect.

Generally speaking writers on this subject fall into two categories:

(a) those who write from an academic standpoint

and (b) those who write from practical experience.

The writer believes that Asimow represents the former category and Marples and Booker the latter. The former point of view is probably the best basis from which to pursue design research, the latter more useful to provide case material to use in the teaching of design.

A very interesting description of the process by a person who has both practical experience and academic status in the design art has been given by Chaddock 1967.

<u>Origins</u>. The design process commences with an expressed need in some form, and work begins in an environment of already accomplished hardware and an atmosphere of knowledge of the relevant arts. Precedents and experience exist.

It is very pertinent to note, however, that the need expressed by the customer in whatever form may require analysis and restructuring before the designer recognises the actual requirements - the real need - behind the initial specifications. Redefinition in the light of developing understanding is not uncommon. Needs analysis is essential. (Rossman 1964, Asimow 1962, Glegg 1972).

This may take the form of a series of questions, e.g. Needs Analysis.

By Content
1. What was the origin of this need?
2. Who has asked for it and why?
3. What does the expressed need represent?
4. What category of system is involved?

By Context
1. What do I know of that is similar?
2. What field of experience is relevant?
3. Where can I find out more about it?
4. What information is available?

5. In what environment will the design operate?

By Purpose 1. What is the result to be obtained?

2. What problems arise?

3. How can this need be re-structured?

The answers to these and similar questions will enable the 'Real Need' to become apparent. A very effective way to work is to use a design workbook and to record everything in it. Used not only as a record - perhaps in journal form - but also as an interactive thinking system - a mirror in writing of one's thoughts - asking and answering each question in turn.

It is said to be characteristic of the Real Need that it may, eventually, be specified without including in the specification any explicit means whereby it may be realised, i.e. it is a general functional specification (performance specification), dealing in concepts only.

Ideas. Commonly images come to the mind's eye, associated with the relevant technology, or that which is regarded as relevant. These will be a function of the extent of knowledge and depth of understanding peculiar to the individual designer. "The conception of basic solutions to a need, even one solution, depends initially on a knowledge of precedents over as wide a field as possible. Such knowledge can only be accumulated over a period of time". (Booker 1962) That is to say, the designer builds up a matrix of experiences recorded in his mind, deliberately packing away the records of his curiosity and imagination. He will have available therefore precedents in the relevant field of technology - the physical embodiments of natural principles that once were inventions and now form the elements of machine systems (Leyer 1974). Hence the value of exposure to the practice and environment of an engineering manufacturing organisation as soon as possible.

In practice, pressure of time and restraints imposed upon the designer from the nature of adjacent structure and by prior decisions, often dictate acceptance of the most obvious adaptation of a previous design of proven merit. This may well be seized upon as 'the answer' to the problem of providing a means to fulfil the need, and no other be entertained. This may be a common, but not the most effective, way to produce the optimum design.

It is characteristic too that although outside influences may restrict choice, the active mind of the designer carries on pondering the problem of fulfilling the need - so that, often after critical decisions have been taken, more and conceivably better (i.e. more efficient) ideas spring to mind.

Whenever possible an open mind should be cultivated, and design office work programmed so that the designer has time to analyse the need, thoroughly restructure and redefine, and devote himself to a period of idea generation alone. He then deals solely in terms of conceptual schemes and systems, using his creative faculty, intuition, and imagination, either individually, or in a selected group.

Evaluation. The process of assessing a list of ideas should be a distinct phase of the feasibility study. As we shall see in the later notes, to mix up the business of creating ideas with that of criticising them is inimical to the effective development of a range of alternatives.

Apply the three test questions to each alternative proposal in turn:

1. Will it work? Does the proposal violate a natural principle, or 'law of nature'? Is it kinematically correct? What evidence is there of the validity of the proposal? Has a stress/deflection analysis been made? What is its dynamic behaviour?

2. Can we make it? Is it physically realisable? (Asimow 1962). Are there intrinsic impossibilities of assembly? Can it be made with available processes? Does it demand unavailable materials? Is its form acceptable?

3. How much will it cost? What is it's economic worthwhileness (Asimow 1962). Are the materials expensive to buy and/or procure? Does the proposal require expensive processes? Is the labour content excessive? Is the handling content excessive? Does the proposal offer future potential for development?

Choice. The recorded answers to these questions for all the alternative proposals constitutes the marshalled evidence upon which a decision will be taken. It is likely that most of the alternatives will have been excluded on one count or another before the end of the evaluation exercise is reached. Those that survive compromise a set of potentially useful design proposals. It is most probable that one only has to be selected from the set.

The difficulties of making this first major critical decision have been well described by Booker and Asimow, and the power of a model of the design process in terms of decisions has been researched by Marples 1960.

Preliminary Design. This stage conventionally commences with the taking of the critical decision which will decide the future direction and emphasis of the design process.

Design Decisions. It is appropriate here to take some notice of the importance and nature of a decision.

Examination in detail of the design process shows that it proceeds in stages, each marked by the taking of a decision. Marples designates them as critical decisions since the path of the design is determined by them. Many others are taken by the designer of a minor nature, e.g. to obtain information, to calculate, to make drawings, etc.

The critical decision has a number of features (Marples 1960).

1. It is most often taken by some person higher in authority than the designer, who has evaluated the alternatives and presented the evidence.
2. The decision is treated as irrevocable.
3. The activities of the design team change at the time of the decision. From considering a set of design proposals they turn their attention to the sub-problems associated with the authorised choice.

Accordingly one notes that the evidence upon which such a decision may be taken has to be communicated and so presentation is clearly an important skill for the designer.

In the marshalling of the evidence for this - or indeed any design decision right throughout the process from feasibility to the final detail stages, another important skill to be cultivated is that of prediction.

The main question to be answered is:

"What will be the consequences of adoption of each alternative design proposal?"

This requires the designer to:

(a) Visualise the resulting hardware and its service usage

and (b) Predict the outcome.

Visualisation. This comes most readily to the designer having an extensive matrix of experience of the relevant machine elements and assemblies. Drawing remains the main technique, although soon to be supplemented if not supplanted by interactive computer visual techniques. Modelling, especially for process plant layouts too. (Chaddock 1967).

Behaviour Prediction. Outcomes predicted on the results of the analysis of behaviour of models of the design proposal system. These are most usually symbolic models and mathematics is the tool of analysis. Frequently experimental methods also. (Siddall 1972, also Marples 1960).

Hence the sub-problems arising.

The basis of comparison between several design proposals must be found not only in the original need (performance specification) but also in a value system which includes of course the beliefs and feelings the designer may have about the respective proposals.

The setting up of criteria against which to judge the proposals, and then the informed choice which becomes the design decision is the final step of the stage.

Design Development.

The general arrangement of the chosen design proposal builds up steadily as the elements of the system become defined and as sub-problems are overcome or eliminated. Commonly experimental studies as well as the results of calculations are constantly used to verify choices.

Continual co-operation should exist between the design team, and the production team whose job it is actually to schedule and carry out the construction and assembly of the hardware. Quality is best assured in that way.

As the design task progresses and the process becomes less concerned with abstractions and more with well known and understood machine elements and assemblies, so the cycles of analysis-synthesis-evaluation and choice become less subjective. Confidence in a successful outcome rises as the designer sees familiar work ahead and can foretell more accurately the outcome.

The stage of detail design shown as a separate activity in the design process is quite often commenced and in progress before the preliminary design of the overall system is complete. Reference to Booker 1962, Marples 1960 and Whittle 1945 provides examples of this concurrent working. Seldom is a machine design so original that all details are innovations. Those elements and assemblies that are well understood and defined can often be designed in detail and constructed in advance of the remainder to advantage.

Even at the relatively defined level of the design of element details, scope for individual style exists. The designer always has choice and his decisions will include aspects of his own value system: his personality.

The seeking for an optimum choice where, for example, a high ratio of strength to weight in an element or machine structure, or a high ratio of power to weight for a propulsion plant is of the first importance, is aided by the use of various analytical optimisation techniques such as that of Johnson 1961 for machine elements, and those described by Siddall 1972, Haug and Aorora 1979 and Wilde 1978.

The latter stages of the design process from the first testing of the prototype through the inevitable design developments to the 'Mark 1' product and its market performance are probably some of the most interesting, e.g. see Booker's description of the development of the bellows restraint units, in particular the care devoted to the verification of the details of the assembly. Also the development and progressive testing recorded by Whittle as his experimental gas turbine became increasingly reliable and airworthy.

From the Design Office itself the final product probably should take the form of:

1. The designer's work book - a record of the particular design process, as a journal and casebook of calculations, evidence, choices, decisions, reports, test results etc.
2. The set of drawings. Project (Proposal) Drawings, Design layout sketches and drawings, Drawings for the workshops, Drawings for Technical Illustration.
3. The written specifications.

Items 2 and 3 constitute the written message to the workshops prescribing exactly what is to be constructed and what performance is required.

Hence the product for the market place.

Drawings. These are the visible expression of the design office's and the drawing office's mental activity (Leyer 1974). They constitute a record of the design as a considered proposal:

1. They define the form - the required geometrical properties, i.e. the relative location in space of the pattern of points, lines and surfaces which make up the shape of each element and assembly.

2. They list the materials and hence indicate the physical properties of the constituent elements.

3. They define the morphological measures of all the dimensions, fits and surface finishes.

Specifications. Should amplify the drawings, describing all those detailed aspects of the choice of materials, processes and finishes not easily or conveniently laid down in the drawings. Should include recommendations for sources of supply, and parts to be bought out, standards to be observed and schedules of tests to be carried out.

Assessment of the Product. The customer will inevitably criticise the product, and if he is lucky, the designer should get feedback under the three headings of Performance, Maintenance and Endurance.

In conjunction with his workbooks, these comments will enable him to go on to provide even better hardware the next time round the Design Process.

The Intellectual Skills of Design

It is pertinent to ask what intellectual skills are exercised during the design process, in order that effective design activity results. Identification of such skills should help to make a relevant education and training available to students of design.

The evidence from which we may identify the skills, and predict the kind of talents we seek, is to be found in descriptions of the design process, not only by the designer but also criticisms and reviews by his associates and colleagues. That is, casebook records, case histories and biographies of designers.

However, it is necessary to bear in mind that the objective is not simply to educate designers in design practice as it may be at present, but to try to equip them with the understanding to enable them to develop for themselves a design expertise for the future.

Intelligence. Intellectual awareness of the environment and the interaction between self and the environment. Customarily associated with an alert, positive, keen eye and ready response to external stimulii. Fundamental to motivation and observation, essential basis to exercise of creative effort.

Curiosity. Desire to observe, explore, examine and find out. Manifest by frequent questioning and persistent attempts to manipulate things, dismantle and re-assemble. Fundamental to the development of a background matrix of information, familiarity with and understanding of any field of endeavour. Another contributing aspect of motivation and perseverence in the search for knowledge and solutions to problems.

Perception. Use of all senses in response to external stimulii and interpretation of the neural messages received. Especially valuable to the designer is visualisation. Rarely is any specific training given in this skill (McKinn 1972, Adams 1974, Abercrombie 1969).

Internal visualisation, that is, the ability to manipulate and interact with mental images of element form, and assemblies, is a valuable skill to develop. Lately this may be supplemented and extended in scope and power by use of a computer visual system.

Analysis. Skill in logical deductive and inductive processes applied to models of problem situations, either symbolic or iconic. Linked with perception is the ability to perceive the essentials of a situation so as to be able to derive and describe a model useful for analysis.

Convergent thinking skills.

Synthesis. The ability to manipulate concepts, to associate, combine and re-combine and to call upon a diverse range of fields of experience in the creation of solutions to a problem. The basic skill is creativity which we discuss below. Linked with perception too is the ability to perceive that alternative courses of action may exist to achieve an objective.

Divergent thinking skills.

Foresight. Skill in predicting the probable consequences arising from the adoption of any particular alternative course of action. Hence the perception of sub-problems likely to be encountered. Foreseeing outcomes.

Judgement. The skill of utilising the studied results of exercising perception and foresight to assess the alternatives and place them on a scale of values with respect to a set of criteria.

Reality (utility) judgements are made using measures resulting from calculations or experiments to assess alternatives.

Value Judgements, made intuitively, that is on the basis of beliefs and feelings, to assess alternatives.

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III. KNOWLEDGE AND CREATIVITY

Knowledge - The Essential Pre-requisite.

A body of bits of information concerning a topic, which has been constructed in the memory as a matrix, so arranged as to be inter-related according to sequences and patterns. It may be used simply as a store from which facts are retrieved as required, or it may be used as a discipline, a tool to deduce behaviour and foresee responses to proposed changes in a system under examination.

Knowledge is a powerful enabling resource for the enlightenment of the possessor, and the manipulation of things and people in situations. With the understanding conferred by well scanned matrices of information, the intelligent person can anticipate the behaviour of systems and foresee consequences of actions contemplated.

The pursuit of knowledge for its own sake is the classical pre-occupation of education. It is especially associated with the conventional image of the university. Education may be seen as the method of developing knowledgeable persons - persons of learning and erudition. Engineering education, adopting this principal objective, therefore develops knowledgeable persons in some of the scientific and technological disciplines associated with engineering as a profession.

More than mere possession it is necessary to be able to categorise, analyse, relate, and seek to extend and to manipulate the patterns of knowledge in the memory. Because the practice of engineering calls for the application of knowledge in the purposeful pursuit of an objective.

Gathering Knowledge.

The kind and variety of knowledge is a function of a person's perception, his capacity and the motivation behind the need for the knowledge. We may recognise that knowledge crammed for the purpose of passing examinations differs from that acquired in order to progress a design study. The former may soon fade from memory since the objective is to achieve a pass grade, but the latter will probably become part of the designer's knowledge matrix since it will have become a foundation for ongoing studies. Motivation to use the skills of perception to study situations in the physical world is the factor of fundamental importance.

Exposure to sources of information may result from a deliberate search, or from incidental observation. The environment bombards every person with a great quantity of information of every kind. However, the attention given inevitably selects that which is regarded as relevant. Sources of particular information are to be found in the library records of the various disciplines and for engineers, the additional range of codes of practice, standards and manufactured products. There are also the condensed records and summaries of past work, such as "Engineering Index", enabling rapid search for specific information about particular topics.

The lecture is probably the most obvious initial source of information.

What is a lecture? It is a formal period, usually not longer than one hour, preferably about 45 minutes, during which time a subject of study is discussed by the lecturer, who should be a person having prior knowledge of, and experience in, that subject.

The lecture aims to impart information under guidance - to transmit the considered opinions gained from experience of and upon the subject. It may also demonstrate established principles and theories recognised as forming the foundations of the discipline of the subject.

Where the body of knowledge concerns a science, i.e. the principles of natural phenomena, then the demonstration of those principles takes the form of analytical studies.

A model is described and its behaviour is analysed to uncover the natural laws upon which it operates. The model may be a written hypothesis or an actual physical construction - usually simplified (idealised) to a greater or less extent.

The analysis proceeds by the use of mathematics - or a philosophy, i.e. by logical thinking process, proceeding step by step to the desired conclusion.

If the model is a physical construction, then the analysis is by experiment under controlled conditions, the subsequent analysis of the experimental results, and their generalisation, i.e. by logical inference.

The conclusions reached, in all cases where conclusions are possible, are entailed by the initial conditions and by the logic of the analysis. The well known phenomena are usually easily demonstrated in this analytical manner.

However, where the body of knowledge concerns an art, then demonstration of principles becomes entirely different.

A work of art, which includes all design, and especially industrial and engineering design, is the end result of a process of synthesis, a "putting together" process. It may be seen as the creation of a whole from a variety of apparently unrelated ideas and concepts. The "bringing to rule of what has been chaos". Furthermore, the properties of the whole often transcend the apparent sum of the properties of its parts.

This process is creative, apparently often spontaneous and seldom exhibits logical steps. It is in contrast to the 'scientific method' inasmuch as it is intuitive. The initial conditions do not govern the end result, only the class or type of result. Demonstration formally of this design process is difficult. Knowledge is typically gained from personal experience.

Stages towards Enlightenment.

Familiarity. The initial contacts with the subject of study. The technical terms, and the context of use. Its value and intrinsic interest. Bits of relevant information. The outlines of a frame of reference.

Knowledge. Not simply the casual possession of a number of bits of information. Some sort of a pattern is soon established so that a system of associations grows and 'makes sense'. Therefore items of information as they are recognised and accumulate have value. This value is analagous to the significance attached to the closing pieces of a jigsaw puzzle. The intense search, then the perception of the pattern relevance as pieces are scrutinised and turned about, to the release of tension as the picture is completed to the last piece. As a complete relevant pattern the pieces are remembered and can be recalled because of the associations of their context.

In such a manner the frame of reference - or 'matrix of experience' must build up. So a fact, for example, is not an isolated thing; it has relevance to other facts, and a value accrues to it according to how the designer sees it fitting into and modifying the matrix.

Understanding. Making use of the matrices of knowledge stored in the memory. The matrix provides a consolidating system for gathering more knowledge as well as a retrieval system for its re-examination. The sequences and patterns within the matrix provide paths whereby memory functions. Degrees of knowledge of a topic correspond to the range and completeness of the relevant matrix. Bits of information within a pattern of associations could be seen as vectorial in nature. One may imagine each fact (for example) as having an arrow associated with it. The length proportional to its place in the pattern and feathers where number indicates its value, or hierarchical level.

Motivation promotes the desire to increase knowledge and operates to survey the existing matrices (state of the art), and impel their extension, as well as periodic review. Repeatedly treading the paths of memory, items become revealed in closer and more significant relationships to existing and developing patterns. Values increase as understanding is established.

To tread and re-tread the established paths within a matrix of information becomes easier with repetition. But, to establish new paths, make new links between bits of information and/or patterns, otherwise bounded by the constraints set by custom and habit, demands mental energy to form, and to consolidate them. The ability to survey ones knowledge with the penetration given by understanding, and then to be able to re-organise and recombine within and between matrices to take new viewpoints and a more profound appreciation is a distinct intellectual attribute.

It is this power which enables a person to produce a number of ideas for the solution of a problem, i.e. it makes him 'fluent' with ideas. The nature of the range of ideas produced, the categories into which they may be divided, accounts for the 'flexibility' with which a person may manipulate his knowledge.

The possession of a considerable store of knowledge does not, of itself, guarantee the ability to manipulate and to make use of it.

Analogy and metaphor are two principal tools used in the manipulation of knowledge; relating bits of information and matrices by the perception of common concepts.

Humour is the most commonplace example of the everyday manipulation of knowledge; making apparently bizarre comparisons between matrices of experience (Koestler 1964). Directing attention in this way, inviting consideration and analysis of unusual comparisons is an arresting and often fruitful way of manipulating knowledge. This ability and willingness to use deep perception to uncover common themes is a key tool for the designer when he encounters complex design situations.

Engineering design is a multi-disciplinary based activity. Designers tend to develop their interests broadly as compared to Scientists and Technologists, who tend to concentrate upon their speciality; even to a single discipline.

CREATIVITY - AN ESSENTIAL INGREDIENT

What is meant by "creativity"? It is that intellectual ability which results in the synthesising of original and worthwhile ideas for elements, machines, processes and systems to satisfy the legitimate needs of people.

How can it be recognised? Consider this description of a classic example of engineering creativity

"As is well known James Watt invented the condenser for the Newcomen steam engine and this, together with other inventions of his, opened the way for the general application of steam power. Watt became interested in improving the engine when he discovered while repairing a model at the University of Glasgow, that its mode of operation was extremely inefficient.

In the Newcomen engine, power for each stroke was developed by first filling the cylinder with steam and then cooling it with a jet of water; this cooling action condensed the steam setting up a vacuum behind the piston, which was then forced to move by the pressure of the atmosphere. Thus with every stroke the cylinder was alternately heated and cooled, and calculation showed Watt that this process was extremely wasteful of the heat applied to the engine. He reasoned that if he could prevent this loss of heat he could reduce the engine's fuel consumption by 50 per cent, an accomplishment that was obviously worthwhile. Watt worked on this problem at intervals for two years but could find no solution to it. Then on a fine Sunday afternoon he went for a walk, and in his own words (quoted in Smiles 1904), this is what happened.

'I had entered the Green by the gate at the foot of Charlotte Street, and had passed the old washing house. I was thinking upon the engine at the time, and had gone as far as the herd's house when the idea came into my mind that as steam was an elastic body it would rush into a vacuum, and if a communication were made between the cylinder and an exhausting vessel the steam would rush into this vessel and might there be condensed without cooling the cylinder - I had not walked further than the golf house when the whole thing was arranged in my mind.'

Watt had then conceived his condensing steam engine and had laid the way for later developments of this type of prime mover during the period of the industrial revolution in England. The essential points in his experience from the standpoint of creative thinking are as follows:

Watt had set up for himself a problem which, after two years of work and intensive thought he had failed to solve. One day while indulging in a reverie during the enforced idleness of a Scottish Sabbath, the solution of the problem came to him, unexpectedly and without effort." (Lewis 1968)

How does this example of creative design in engineering correspond to the view of creative thought taken by psychologists?

Wallas (1926) proposed that creative thinking falls into four phases - Preparation, Incubation, Illumination (Insight) and Verification. Very similar stages have been perceived and described by other writers, not only psychologists, and notably Von Fange 1959, Haefele 1962, Ghiselin 1955 and Koestler 1964.

It is interesting to notice that no matter in which discipline the creative thinking process has been observed, the same set of stages has been perceived. Clearly creativity is a common intellectual ability in art, engineering, biology, management, physics, medicine, advertising, and so on. Koestler has probably done more to relate the creative acts in a variety of disciplines than other investigators. The present writer suggests that creative thinking in engineering has the greater potential for changing mankind's condition and environment than in any other discipline. (Satterthwaite 1979).

A few notes on the four stages of the classical model of creative thought:

<u>Preparation</u>. The essential preliminary work to develop familiarity with, knowledge of, and eventually understanding of the context and content of the problem. Note that Watt spent two years in preparation before his insight occurred. It has been said that "Fortune favours the well-prepared mind". It is a period of intensive research and study in <u>preparation</u> for the illumination to follow. Motivation is important, discontent with the unsolved problem situation, incentive to persist in the search.

<u>Incubation</u>. This next stage or phase is the mystery. Observation of the behaviour of creative people and their introspective accounts of creative acts - e.g. that of Watt above - verify that such a phase <u>does</u> exist. The conscious mind seems to tire of the whole business and consigns the problem in all its aspects to the subconscious. The creator turns his attention elsewhere - possibly in despair of ever achieving a solution or,

with past experience, deliberately takes a rest and changes his attention to another sphere, in the almost certain knowledge that, as incubation has worked for him before, so it will do so again! Sometimes the problem re-surfaces and an intimation of a possible solution may appear - from time to time indications come to the conscious mind that after all that problem is still being considered in the unseen recesses somewhere. Koestler's model of the creative act postulates that in some fashion a search is being made of the matrices of experience in the memory, that comparisons are being made, and that sub-consciously there is still a lot of work being done.

Illumination or Insight. Comes quite often to the conscious mind in a flash of revelation - as did Watt's idea for the condenser. Probably almost immediately the conception will be filled out by the mental images of how the idea can become a physical entity, especially so for engineers. It seems that insight is achieved during a period of mental and physical relaxation, after the hard and frustrating preparation. That relaxation by all accounts is essential - note Watt was relaxing during a pleasant walk in country surroundings.

Similar cases are quoted by Ghiselin and Koestler, and quite similar experiences are described in case histories of engineering design.

Verification. A process of reflection and study. Is this insight really as good as I thought it was when first it came into my mind? For Watt it was the experimental work of constructing a condenser as he had visualised it and trying it out to verify that it would work! This is probably most often the way in which engineering design insights are verified. See the case material distributed.

It is the epoch-making examples of insight which achieve the most publicity, e.g. Watt and the cases assembled and quoted by Ghiselin and Koestler, since they represent radical departures in the stream of human thought. In engineering they represent radical changes to the main streams of technology. However, creative thinking is not restricted to such cases and is not the prerogative of the exceptional designer in the most senior positions. Creativity manifests itself at all levels. For example:

Consider the ingenuity embodied in this hexagon-pentagon cap for securing connecting rods for steam locomotives. The fact that steam locomotive technology may be regarded in Western countries as obsolete is quite beside the point. It is the creative thought that went into this

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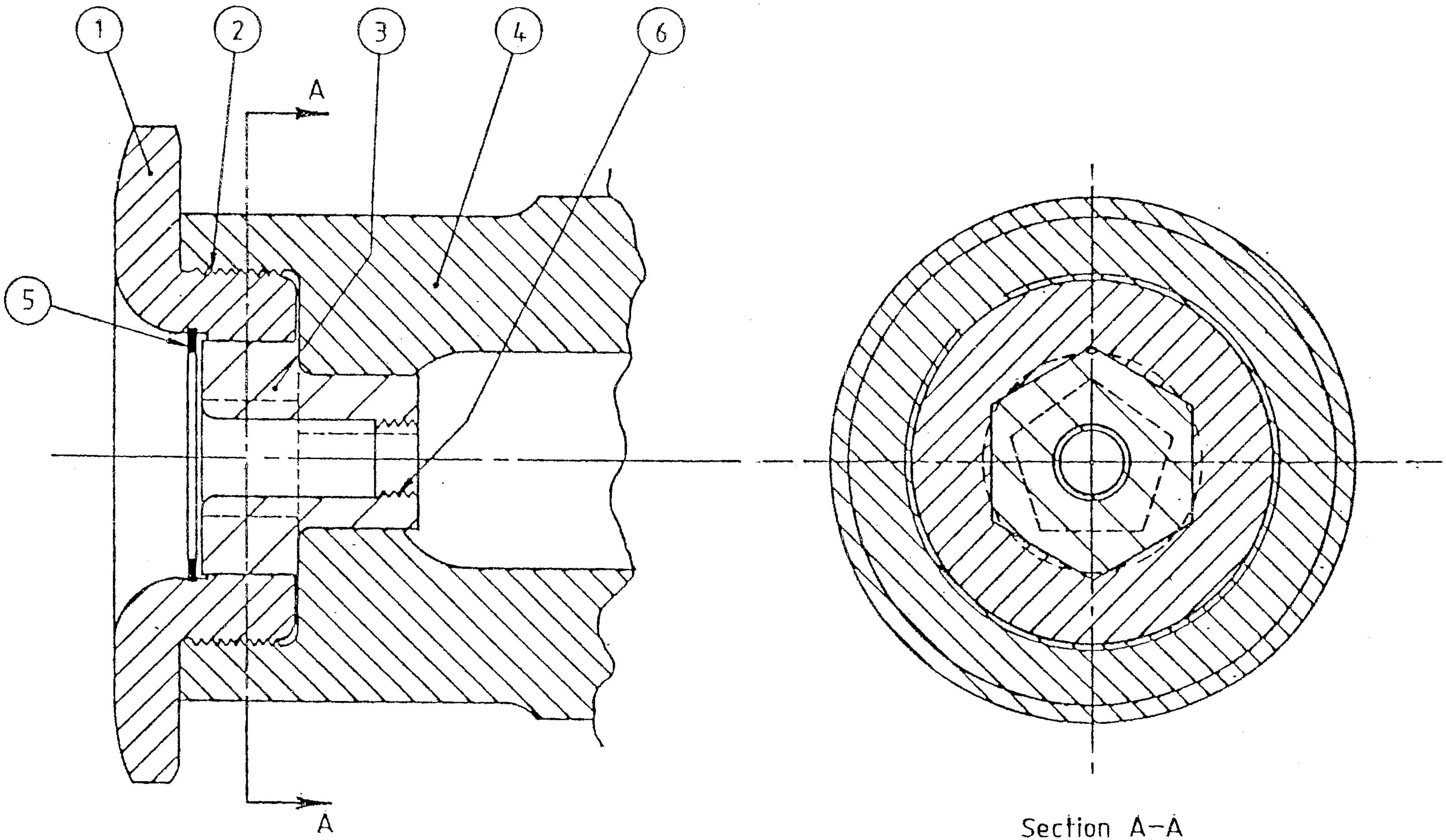

R. Curl's hexagon-pentagon cap for securing coupling rods. After fitting the coupling rod the securing cap 1 is screwed on by its 4½ inch diameter 8 tpi thread 2 and further tightened till the check 3 will slide into both the pentagonal slot in the crank pin 4 and the hexagonal slot in the cap 1. The check is then held in position by circlip 5. A thread 6 is provided for entry and withdrawal of the check. The pentagon/hexagon allows 30 positions per revolution of the cap so each represents an axial movement of 0".004 and thereby allows a fine fit.

design of a significant machine element detail that matters. (Bulleid 1977). See sketch attached.

As with any ability, talent for creative thought varies from person to person. For the designer, creative ability is a very important part of his overall intellectual structure. So it should be taught (Satterthwaite 1979).

Perhaps more than the analytical mode of thinking, creative thinking is significantly affected by the mental state of the thinker.

Obstacles to the achievement of insight:

Internal - functions of the personality: such as: Perceptual blocks. Perception is more than the reception of the stimulus at the retina of the eye, an act of interpretation is automatic and is systematically carried out on the basis of habitual memory. All memory inputs are classified and stored in the matrices of experience. Responses and reactions are governed by the content and accessibility of these matrices. A process of pattern comparison and recognition seems to be involved. There may be internal mental blocks to perception so that there is an inability to perceive implications behind observations. Incorrect interpretations of memory inputs may occur. An inability to isolate a problem from its context, to recognise and define the attributes of a problem situation. Perceptual habits induce mental 'set', often very difficult to change.

Cultural Blocks. The process of the rearing and the education of children is bound by its very nature to develop in the child a set of ingrained beliefs. These may or may not encourage an open mind to the creative process. Some aspects of culture which may not are: Pressures to conform to social norms which prevent free interpretation of perceptions and experience. Worship of rules and regulations. Lack of verbal expressive facility, poor vocabulary, leading to constraints on thinking. (Expressive block). Over-emphasis on competition in the culture - or on co-operation - or reliance on authority. A general negative outlook on life from the social climate.

Emotional Blocks. Inability to break free of hampering fears and attitudes, "Catastrophic Expectations". Worry due to chronic pressure of daily life. Over-motivation. Distrust of associates. Excessive faith in logic. Self satisfaction. Fear of mistakes, of failure, of looking foolish.

One can say that all these internal blocks to a free conceptualising are symptoms of a lack of mental stability and balance. However, this does not of itself offer help to the designer who may be a victim to some degree of some of these intellectual constraints. Whilst we may require mental stability and intellectual maturity, it is not easy to see how to engender its development in the context of university or industrial life. (Adams 1974, von Fange 1959, Abercombie 1969).

External blocks. Functions of the environment.

A management/organisation structure that has no room for creative persons. The inertia of institutions. The reluctance of society as a whole to accept change, e.g. Mozart's operas, Mendel's study of inheritance, Darwin's theory of evolution, etc.

The absence of acceptance of design activity as being worthwhile, and of a merit equal to that of Sales, Production and Administrative activities. An adverse climate to creation. Chronic pessimism on the part of one's colleagues towards one's original ideas.

AIDS We may now recognise that there are many aids to the development of insight. Techniques which will help designers to attain and exploit an open mind.

The structuring and re-structuring of the given data in association and combination with the matrices of memories and experiences already available to the designer. The mental energy to do this carries over from the 'Needs Analysis' which should already have been carried out, and the 'Real Need' definition which should be in the workbook before the designer's eyes. Frustration may be the background feeling, but one has to learn to be tolerant of ambiguity and chaotic states of one's data in the early stages of the search for ideas. This tolerance and emotional stability under pressure is a great asset to the designer. The eventual thorough understanding of the situation is the best basis from which to direct an organised search for more and better ideas.

Techniques of search. There are many, but most depend upon some sort of systematic comparison system, e.g. Osborne's Check List, and word association lists (Osborne 1953). A major objective of such a search is to adopt as many different points of view as possible, and in so doing to overcome mental blockages or 'set'. This may be done by the individual designer or by a group of individuals under more or less organised conditions. (von Fange 1959).

Recording Ideas. Every idea and interpretation should be written down at the time of conception. Simply to record is not good enough, the idea should be present in written form before the designer's eyes as he thinks. The process should become a continual evolution of inspiration. Initially no considerations of practicality, no suspicion or hint of evaluation should be permitted, as such would impair the free flow of the conceptual process. Evaluation is a distinct and separate phase of the creative process.

Make maximum possible use of alternative thinking languages. These are the tools for manipulating, the concepts of the mind's eye, e.g. verbal reasoning using language - symbolic reasoning using mathematical logic - visual reasoning using imagery. The designer will use them all in an interactive manner.

The spoken/written word: Even between two persons supposedly speaking the same language, difficulties of interpretation arise and communication may be less than perfect because of the existence of a variety of shades of meaning, e.g. how many meanings has the word "NORMAL".

The descriptive language of literature (prose and poetry) is often insufficiently precise for use by designers - yet, the stark language of science may be of a precision which precludes a creative interpretation. A language that is evocative, emotional and rich in the range of concepts it can associate can be to the designer a source of unexpected creative material, yet it will need to be re-interpreted to develop engineering precision.

Imagery deals in terms of mental images, to manipulate thoughts (concepts) and to describe ideas in the mind's eye giving them a structure, i.e. an image.

Perceptual Imagery. Sensory experience of the physical world. Stored in the memory as concepts associated with some central image (Schemata), e.g. the concepts associated with the central image of a freight train.

Mental Imagery. Constructions in the mind's eye utilising the information from perceptual imagery.

Graphic Imagery. Dialogue between the designer's mind and paper (or computer display). Sketched, doodled, drawn or otherwise displayed and recorded as an aid to memory or to a process of form design and development. An interactive design process.

To transfer the image in the mind's eye on to papers, to record it, and then to effect a rapid alternation between thought processes, mental images and the motor discipline of sketching so as to modify and develop the paper sketch is seldom rapid enough to follow the thoughts. Some direct transfer means between the mind's eye and a permanent display is required.

It cannot be emphasised too often that the process of searching for ideas must not be mixed up with the process of their evaluation. To try to be creative by criticising each idea as it comes along is to keep putting mental blocks across the pathways of search amongst the matrices of experience, and so frustrate one's creativity.

Evaluation comes later - how much later depends so much on the individual designer and the circumstances of the design activity.

Hence the contrast in the nature of the two disciplines, analysis and synthesis. In analysis we customarily commence with some model of a situation whose behaviour we wish to study and measure. We set up a symbolic argument based on the model and the assumptions it specifies. We use mathematical logic to determine step by step how the model behaves and we find thereby a unique answer to the problem. On the other hand in synthesis we commence with a need and we endeavour to provide as many means as we can to fulfil that need, because by inventing many alternative courses of action we have the opportunity of a choice for optimum performance.

In analysis we converge to an answer, in synthesis we create many alternatives, we diverge.

Not many persons are likely to be equally skilled at both activities.

Insofar as it may be possible to model an intellectual process Koestler 1964 offers an interesting analogy. He attempts to provide an answer to the question of how the matrices of experience may be searched, and how the mind associates different matrices in its attempts to find a solution to a problem not so far amenable to resolution. His matrices are planes and he postulates their intersection in a variety of ways as being analogous to the mind's manipulation and association of a variety of concepts. The end of incubation and the moment of insight occurs when a particular set of planes intersects in a particular orientation where at the intersection the higherto unconsidered concept sets off the reaction which springs the illumination of the conscious mind.

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IV. OPTIMISATION - An Essential Point of View

A distinguishing characteristic of engineering design practice is, or should be, the continual search for a better way - preferably the optimum way to solve design problems. Synthesis alone will not ensure recognition of and hence choice of the best alternative course of action.

What is required is that given a number of alternatives, a progressive method of deriving the optimum choice, the best reconciliation of Performance, Maintenance and Endurance for a system. This may be looked upon as the logical extension of the craftsman's pursuit of excellence, a modernisation of design by evolution. This can become an attitude of mind after some experience in the techniques.

Also successive and progressive improvement in detail of a structure or machine, a form of design development practised in depth by mechanical designers, as the result of experience, test and observation.

Designers try to maximise desirable attributes and/or minimise undesirable effects, seeking more economical, quicker, reliable ways of operating plant, manufacturing, and meeting performance specifications.

Therefore a move towards a logical, systematic technique to discover the functions upon which the behaviour of a system depends, and to identify and display the evidence upon which alternative courses of action are going to be assessed.

Note that until the FORM of a design proposal has been suggested it is impossible to imagine and to predict its behaviour in service, and to judge this against any criteria.

So that Form follows Function and Creation must come before optimisation is possible.

1. Essentially one has to decide what it is one is trying to optimise; this is the initial and central problem.

   Frequently, Production Cost is to be a MINIMUM
   Performance " " " " MAXIMUM
   Weight " " " " MINIMUM
   Reliability " " " " MAXIMUM

or often more conveniently

Strength/Weight is to be a MAXIMUM

$\left.\begin{array}{l}\text{Power/Weight}\\ \text{Power/Space}\end{array}\right\}$ is to be a MAXIMUM

2. Functional relationships between all these design parameters have to be established in order to permit of behaviour prediction. Often approximate relationships have to suffice in the early stages of a system design.

There is no explicit way to be sure that <u>all</u> the system parameters have been identified, so that an initial optimisation analysis may prove to be invalid but a step on the way to a more complete understanding.

Suppose we wish to maximise Performance and minimise Cost - can this be achieved simultaneously?

It may be said that the problem of finding that set of parameters which most closely approaches this ideal is one of differentiating the Performance and Cost expressions with respect to the system parameters and setting each equation equal to zero.

The simultaneous solution of the set of equations provides the optimum parameter quantities, defining thereby the one system of the many possible which offers the optimum combination of maximum Performance allied to minimum Cost.

3. Such solutions are obtained in the face of Constraints which feature as limiting values of the parameters, and which define thereby <u>the domain of acceptable solutions</u>.

Frequently there are practical limits on the maxima and minima beyond which it is agreed to be too costly to go. Cost is an overriding constraint, the price to be paid for extremes.

The Three Constituent Elements of the Optimisation Problem

1. The Criterion Function. This is formed by proper choice of the design parameters appropriate to the particular objective. It is usually some utility function which is to be optimised but may be a value judgement when initial knowledge of the design purpose is incomplete.

2. Functional Constraints. The design parameters and other interdependent variables are related by natural physical 'laws' or empirical relationships 'equalities' - defining the mathematical archetype of the system, e.g. heat content is a function of thermal properties and temperature. These relationships must hold for the proposed system to be physically realisable. If they do not then the suggested relationship is an intrinsic impossibility (Glegg 1973).

3. Regional Constraints. Limits may be imposed upon individual parameters in order to ensure physical realisability and compatibility within the context of the system, and its environment. These are 'inequalities', e.g. stress has an upper limit imposed by the material choice and the failure criteria. Space may be limited by adjacent hardware, etc.

For the general mathematical model see Siddall 1972. A variety of techniques has been established for processing the set of expressions resulting so as to optimise the criterion function. Siddall 1972 reviews most of these.

Such an approach to design as this owes nothing to current or past practices. It aims solely to provide a philosophy and techniques to tackle design problems of the future.

Johnson (1961) provides a systematic approach to the optimum design of machine elements.

Cox (1965) does the same for the design of structures of least weight.

The process of optimisation can be applied in two ways or stages:

1. Overall optimisation of the fit between the system under design and its context - or environment - so that:

a. The end product appeals in the market place. It fulfills the need - PERFORMANCE, PRICE, AND ENDURANCE; and

b. Feedback from users to designer is encouraged by the service provided for MAINTENANCE.

Wilde (1978) addresses many aspects of overall system optimisation.

2. Internal design of the system so that it functions most effectively, i.e.

a. Sub-systems are properly matched to their preceding and succeeding systems. PERFORMANCE is maximised; and

b. Structural elements and sub-assemblies are designed for economical manufacture, easy assembly and economical MAINTENANCE.

French (1971) is a good reference for mechanical systems. Haug and Arora (1979) provides a deeper mathematical treatment following Siddall.

A considerable literature exists on the topic of optimisation in general.

As a point of view, the search for an optimum, the pursuit of excellence and the ideal of a well balanced design has a strong aesthetic appeal. The philosophy may also be applied to such considerations as:

1. What is the optimum degree of refinement for this analysis?

2. What is the optimum time to devote to this problem?

3. Will the increase in capital cost be worthwhile as compared to the probable decrease in maintenance costs?

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Wilde, D. See page 17.

V. THE DESIGN FUNCTION IN INDUSTRY

Growth is the common phenomenon to all Western style commercial enterprise, i.e., from small beginnings to a developing physical size and organisation complexity. Apart from the obvious connotation of physical size, we can recognise a growth in technological sophistication which we hope represents a better product from the organisation, better meaning more efficient performance - a closer satisfaction of the performance specification, and of the customer.

Thus, a reason for growth may be found in the desire of the directors of a manufacturing company to make use of increased resources of technology and talent to produce a more satisfying product and to do so before their competitors in the field and so secure increased sales and profits. Growth in this sense means therefore increased satisfaction to the company's directors and to the company's customers, and therefore an increased profit to the company's shareholders.

To the Managing Director such growth may satisfy his ambitions for the company and probably his personal ambition for satisfaction in his profession which is reflected probably too in an increased status with his board and his shareholders, and represents an increase in his personal power.

To the Chief Designer and his staff growth may offer similar satisfaction if it represents and springs from the development of the design work which has come from their office and provides the designs upon which the hardware has been based which, when sold in the market, has yielded the growth in profits to the company.

Thus the company's growth results from design development, and is and remains design oriented. The design function in such enterprises is clearly and obviously the source and spring of the company's products and therefore of its growth (Wilde 1979, Leyer 1974).

The case histories quoted above illustrate such growth in several forms. Smyth's development obviously provides an economic way to help process the manufacture of the vast numbers of cans used today - thus the growth in the can manufacturing industry owes a lot to his design endeavours.

An epic story of growth is illustrated by Whittle's invention of and development of the jet engine. From virtually one man, to a small organisation such as Power Jets, to the rapid growth initiated by the interest of Rolls Royce and similar companies such as Pratt and Whitney, to the vast amount of resources, material and human, devoted to the design, development, construction, testing and usage of jet engines today. For

Whittle this must represent immense ultimate satisfaction, and similarly for many others associated with him in the enterprise. The design function for such complex, thoroughbred, technology and engineering science based construction must be the central hub about which all other functions revolve. (Whittle, Sir F., 1945).

Similarly for Godfrey Hounsfield and EMI, the growth in demand for such a useful tool as the Scanner has led to a corresponding growth in its manufacturing capabilities. Once more the design function remains the central focus of the developing enterprise. (Wilson, J., 1975)

For the Bellows Restraint Unit, potential growth was a deciding factor in the devotion of resources to its development. For R.W.G. this might have become the basis for company development in a new field if the demand for such large ductwork restraint units had been sustained. (Booker, P.G., 1962)

Where the manufacturing organisation is devoted to the design and construction of complex machine assemblies whose specifications are technically demanding, and where continual innovation is required to meet those specifications, e.g. aircraft propulsion plant and aircraft structures where power/weight and strength/weight are so critical, also plant where economical, accurate and reliable operation over service life: then the design function holds considerable power in the organisation and the Chief Engineer is accorded the status and respect his job merits.

It is therefore no surprise to notice that the best descriptions of the terms of reference of the designer in industry are written by Armer 1964 and Wilde 1979, both Rolls Royce design engineers.

To quote from Armer, p. 28 "The design scheme links the work of the performance and other specialists, including the designer himself, to the practical engineers by translating the theoretical proposals of the former into sound engineering propositions defined on paper in the language best understood by the latter. Until this is done, no practical work can be started. Afterwards, many people in many departments become involved and much expense is incurred in implementing the designer's instructions.

A good designer, as a result of his sound technical training, has a broad understanding of all the sciences associated with his Company's products, but, nowadays, he cannot, nor is he expected to, keep abreast of all the developments on the many specialized fronts of modern engineering. Therefore, a progressive Company must employ many specialist departments to keep the designer constantly moving forward with developments."

"In addition to the influences of the specialists, major design decisions are also normally influenced by several other designers ranging from the Chief Design Engineer downward; but it is the man who prepares the scheme who interprets all decisions and, in the process, makes countless minor ones, far too numerous to be checked by anyone else, yet often of vital importance to the smooth progress of the job and to the quality of the final product. He has to be entrusted to make the decisions and thus he, finally, determines what is to be made and what the customer eventually will receive. Thus, he bears a very heavy responsibility."

"<u>The effect of design upon the product and upon the Company's prosperity</u>.

A design decision which leads to any form of adverse experience causes either:

(a) Loss of time and money in correcting the deficiency, firstly at the design stage and then at every succeeding stage, including the very expensive manufacturing and testing stages, disruption of programmes, loss of profits on the production line for the period of the delay and a setback in the race against competitors; or

(b) If the deficiency is not corrected, the single fault is multiplied at the production line to cause trouble or displeasure for many people in many places and, consequently, injury to the Company's reputation and business.

Conversely, design decisions which contribute in any way to the advancement of the product, compared with competitors' products, will be similarly multiplied at the production line but will enhance the Company's reputation and attract business.

Design is clearly one of the most powerful of all influences upon a Company's prosperity."

Wilde, until recently Chief Designer at Rolls Royce Aero Engines has said in part:

"Today, years of competition to produce machines, structures and processes of increased performance, together with new developments from science, has led to higher degrees of specialisation in all fields, materials, stress and vibration analysis, heat flow, fluid mechanics, acoustics, gas dynamics, new manufacturing methods, etc.

Design staff have to rely more than ever on technical specialists in R & D for <u>information</u> required to work out designs.

However:

The designer often not well enough equipped technically to question the specialists whose recommendations taken together may be incompatible in overall design objectives.

The specialist, rarely able to appreciate the multi-disciplinary interactions the designer has to reconcile.

Nevertheless the designer is still responsible for working out the optimum choice between recommendations of the specialists - to produce a balanced, effective, reliable, safe and economical design. Co-operation between the technical specialists and the designer on the basis of the proposal drawings (at the Feasibility Stage) put forward by the designer for comment by the specialist, is a common arrangement.

Every line on the drawing board produced and sanctioned by the designer will decide what will be made and how it will perform in practice." (Wilde 1979).

Note. Design cannot proceed by asking the specialists questions and trying to understand and use their answers in a design. Only the designer knows the purpose for which the design is required. The drawing becomes the powerful tool by which criticism and development of design proceeds. The designer has the authority to take the decisions, not the specialists.

There is little chance that the design function will be under-valued in, say, aero-engine construction and similar technically demanding industry but in many others, the overwhelming empasis on production, for example, does tend to obscure the importance of the designer and his office.

It is of relevance to speculate as to why the design function in an engineering organisation which constructs and sells products for a living, should be under valued, sometimes to a marked degree, almost regarded as a necessary evil (evil necessity!).

Some reasons might be:

1. Small firm. The owner/founder still runs every management function. The product is the mainstay of the economy of the firm, and after the initial prototype construction and proving to the market product, there is little or no design/development to be carried on. The incidental modifications are undertaken by the owner as and when possible - fitted in between admin. and office work and machine shop trouble shooting. The firm cannot afford a full time designer/ draughtsman, and the prevalent attitude is that the design phase is over. Obsolescence is inevitable.

2. Small/medium firm. Devoted to production of batches of standard products. Concentrates on making the best possible job with current resources. Accepts a lot of sub-contracted work for other companies. Can see no reason to pay and support a designer. Probably employs one or two draughtsmen on not very exciting work. Solvency depends on flow of sub-contracts.

   OR Emphasis has changed from design to Sales and Contracts under influence of a marketing expert. Enthusiasm of Managing Director for his design staff has been channelled to market research in expectation of higher profits and a bigger salary cheque for himself.

3. Medium/large organisation. Probably a branch of an overseas company. Manufacturing and assembling a product designed overseas, in large numbers, even "mass production". Has no scope for a design function but does employ designer/draughtsman on modifications and the occasional in house design job. Solvency in hands of parent company.

4. Comparatively primitive technology. Construction and supply of very well known products on a routine and traditional basis. Adequate but primitive livelihood. Education and training of members of organisation is not adequate to enable them to appreciate the potential power of design, to make their product more effective and their organisation better paid. Some day soon they must prepare to move into a more modern format, and continue to provide a service to a more modern society.

Effects of Lack of Appreciation of the Power of the Design Function

The most significant effect of the under-valuing of design is the consequent low status and discouragement it offers to designers and design/draughtsmen, persons who wish to make a career of designing.

Because the personality of the persons who apply for jobs where design and development is the interest is different from that of other professional engineers or managers. They have within them the creative streak, not at all apparent in others.

Consequently, where design is regarded as a necessary evil there is a tendency towards poor working conditions in the design/D.O., and the treatment accorded design/draughtsmen vis a vis R & D engineers and managers, tends to a high labour turnover (Wallace 1952). In turn the poor reputation the job gathers means that those who take it on are not skilled or experienced designers and one gets the draughtsman in the job who seems to equate design with solving a formula - any formula, to get 'the answer'. This makes of design a dreary occupation. The consequential effects on the company's products are inevitable and obvious.

The Design Function and the Organisation Structure.

See Diagram. Typical engineering organisation structure is bureaucratic i.e. centred about offices occupied by career executives. The work flow is geared to the processing of the administration and the necessary progressing of orders through the manufacturing organisation. This copes with routine but when innovation involving a development of some note - such as a radical departure - is mooted, then the necessary preliminary feasibility study and design work tends to disrupt the routine pattern of investigative work and customer servicing. Hence the Project Office system. This selects a team or Task Force to work exclusively on the Project until it attains the status of the standard product range offered by the company (Wilde 1979).

The customary bureaucratic structure of management is dedicated to a continuance of the organisation. The work carried out by the R & D department, and by the Design Office with perhaps one or more Project Offices, is often responsible for significant changes to the organisation, e.g. a new product, a developed design, or a diversification to a new range of products. There may be some conflict of purpose. Reconciliation of such differences in goals lies in the province of the leadership exerted by the Directors and Chief Executives.

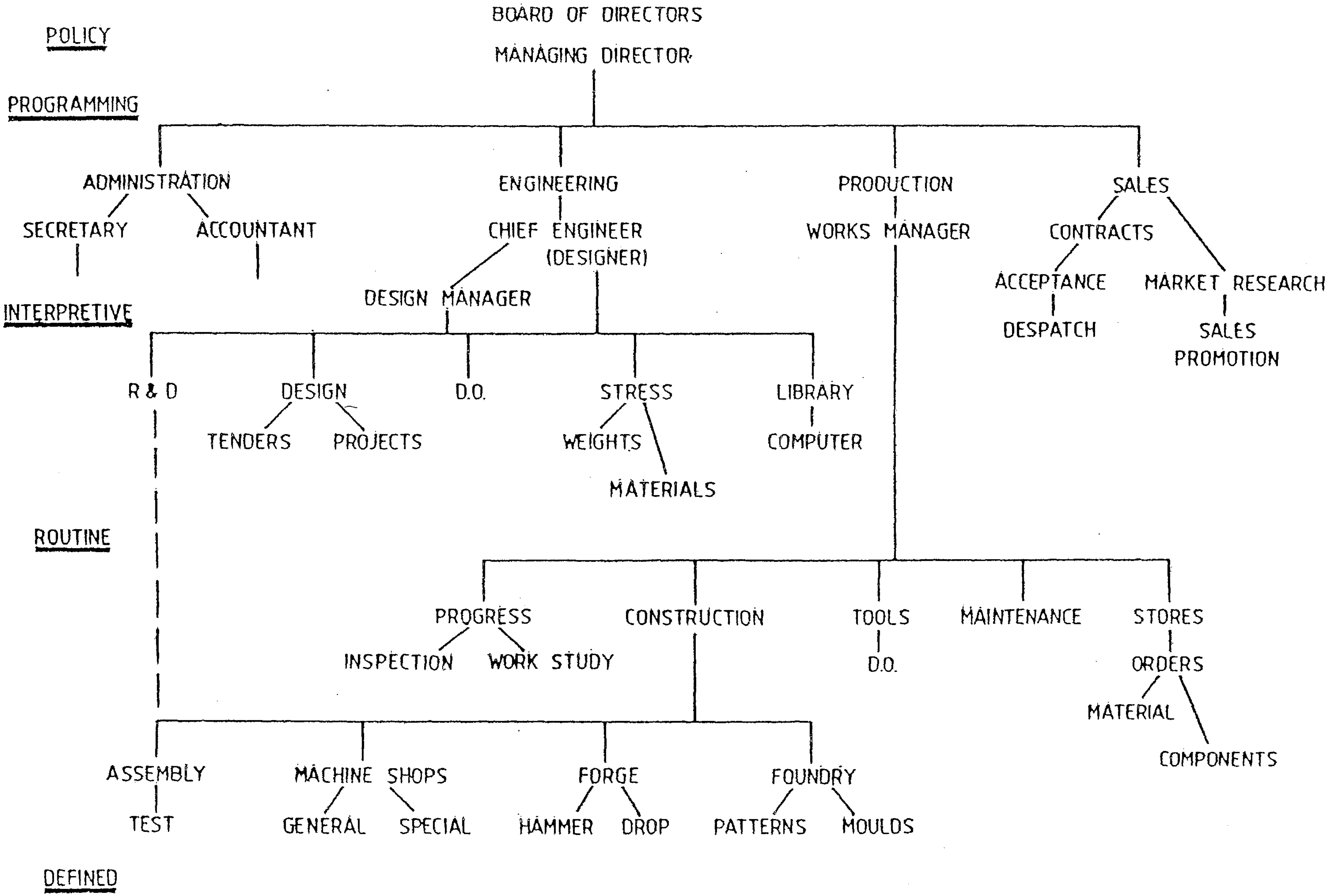
The design function is probably the only principal division within the organisation which puts a premium on creative work.

Whereas most work is carefully scientifically scheduled, especially mass production work, where creation is concerned scheduling is not likely to be a success. How can the engineering organisation predominantly a production organisation, incorporate creative persons successfully? (Asimow 1964). The EMI Company seems to be able to cope (see Case above).

However, resistance to change is a fundamental characteristic of organisations, and a campaign to convince management of the value of a proposed change may be necessary (Von Fange 1959).

How should the Design Function be encouraged and sustained? What should management provide? (Haefele 1962 and Wilde 1979).

1. An alternative career goal for the design engineer to the customary administration and management, i.e. a career as a Designer. (EMI seems to have done this).


BOARD OF DIRECTORS
MANAGING DIRECTOR
POLICY
PROGRAMMING
ADMINISTRATION
SECRETARY
ACCOUNTANT
ENGINEERING
CHIEF ENGINEER (DESIGNER)
DESIGN MANAGER
PRODUCTION
WORKS MANAGER
SALES
CONTRACTS
ACCEPTANCE
DESPATCH
MARKET RESEARCH
SALES PROMOTION
INTERPRETIVE
R & D
DESIGN
TENDERS
PROJECTS
D.O.
STRESS
WEIGHTS
MATERIALS
LIBRARY
COMPUTER
ROUTINE
PROGRESS
INSPECTION
WORK STUDY
CONSTRUCTION
TOOLS
D.O.
MAINTENANCE
STORES
ORDERS
MATERIAL
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GENERAL
SPECIAL
FORGE
HAMMER
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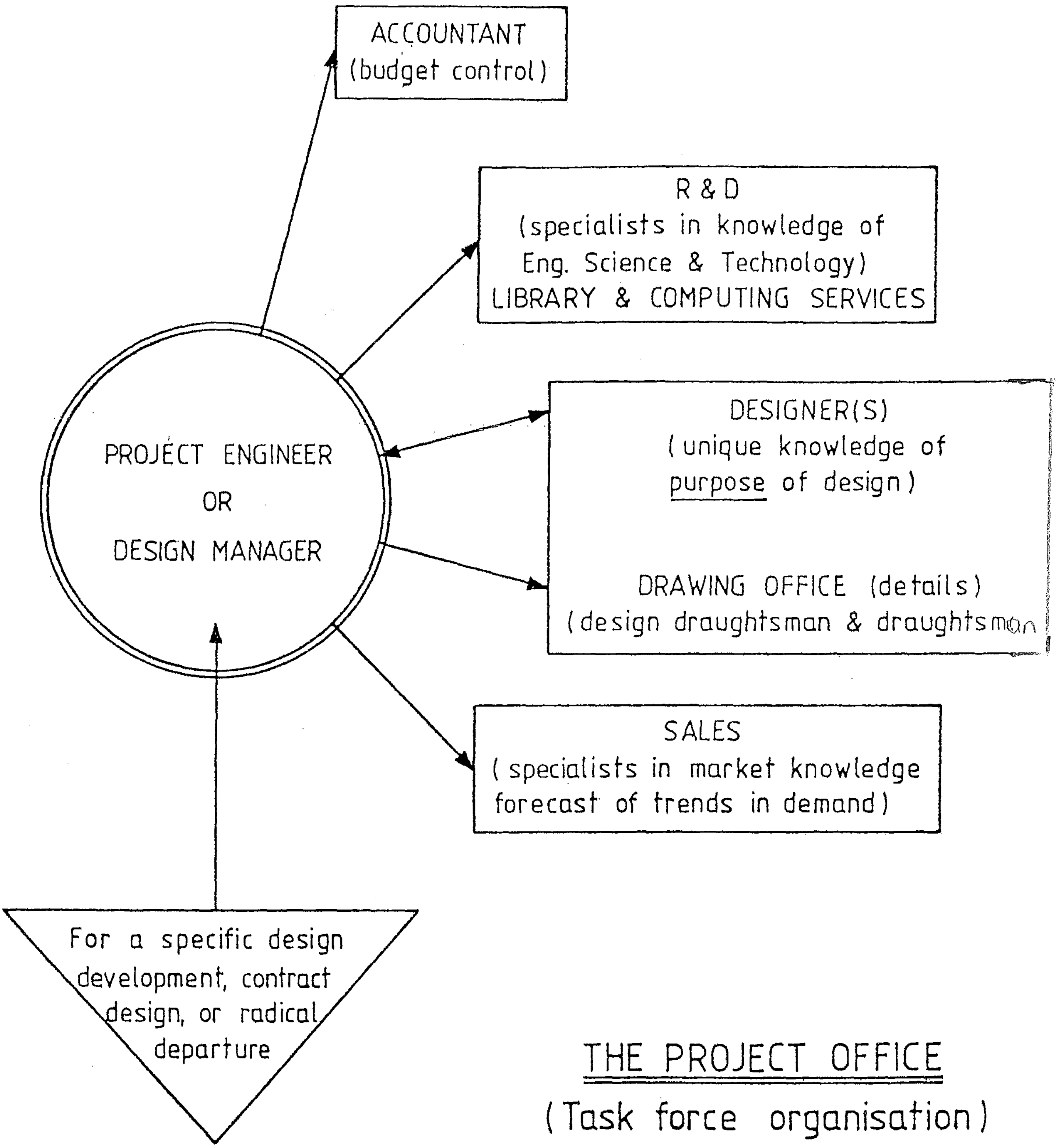

THE PROJECT OFFICE

(Task force organisation)

(ref. Armer, Wilde)

2. Recognition for creative work.
3. Use of creative results as highest form of recognition.
4. Freedom to create, within the company structure, with an assurance of a sympathetic hearing, if not acceptance of creative results. This means freedom of association with colleagues as well as the planned work of current projects.
5. Services exclusive to the Design Function, such as secretarial and technical library facilities.
6. Recording and filing services so that design work may be recorded as it is carried out and be available for call up and scrutiny in the future. (Ref. Booker).
7. Interactive graphical computer aids, as well as the more usual calculation and data storage facilities.
8. Recognised access to Board of Directors as well as to the workshops, test and assembly plants.
9. Educational and training opportunities throughout career.

In the most advanced engineering organisations, the Design Function may well have a Design Manager at its head, whose principal job is to take care of the daily routine programming and the administration and management of the Design Offices. This leaves the Designer(s) free to do that which he is best equipped to do - namely Design. (Crouch 1981, Wilde, 1979).

A Design Manager should have equal status to other chief executives, and to the Chief Designer with a seat on the Board.

Such a system for the Design function may go a long way to raise and maintain the status of design engineers and enable creative persons to relate to others in the organisations more effectively.

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VI. THE DESIGNER

Who is this person? What distinguishes him and sets him apart from other people - other engineers?

1. His works. He produces designs and becomes known by results initiating change. Especially apparent to his peers and colleagues. These products are characteristically apt and ingenious. e.g. Barnes Wallis, Sydney Camm, Henry Royce, James Watt, Alexander Graham Bell, Henry Maudsley, Brunel, and so on.

2. His motivation. High and Persistent. Frequently seeking answers to problems he has foreseen and defined for himself.

3. His curiosity. Directed over many fields, resulting in a wide ranging knowledge, and variety of interests.

4. His creativity. Often exceptional and advertised by the fluency and flexibility of his ideas.

5. His tolerance of ambiguous, ill defined situations, with equanimity.

6. His preference for ideas and purposeful construction, to people and social groups.

How does he get like that? What conditions his personality, his attitudes, feelings and beliefs?

1. Genetic inheritance. Source of fundamental talents.

2. Family style and environment, especially early childhood. Sets interests, attitudes and beliefs, psychological health.

3. Formal training and education. Develops (2) as well as skills and knowledge. Places person in the social scene.

4. Daily experiences at work and leisure. Encourages or frustrates the designer in his developing style and search for self-fulfilment.

A model of the design process, to be complete, should include the designer as a psychological individual in all the aspects noted above. It should also account for his interactions within his design team as a social group, and the corresponding behaviour of the group within the organisation and the organisation within the environment. A socio-technical system.

What value would such a model possess and to what purposes might it be directed?

1. Satisfaction of curiosity and increased knowledge.

2. A better understanding of design as an intellectual discipline and organisation function.

3. More effective education and training for designers and, in fact, for all persons as a consequence.

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CROUCH 1981, see page 45.

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ROSSMAN, 1964, see Page 6.

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APPENDIX 2

1. Syllabus of Engineering Design 3 (Mech. 1981).

2. Assignment Papers set: No. 1 - 1981, No. 2 - 1979 & 1984, No. 3 1979.

3. Design Studies: First term lists for 1981, 1983 and 1984.

4. Design Studies:

   Second term list - undated.

   Handout sheets for individual studies:

   (a) Westland Port development.

   (b) Plant for Proof Testing Gas Turbine Rotors.

   (c) Conveying system for Inky Black Mine.

   (d) A 600 SHP Marine Gas Turbine.

   (e) A Steam Turbine/Generator for Sugar Plant.

   (f) Design for a Constant Volume Bomb.

5. Some Notes on 'Teaching' Design.

6. Some Notes on the Presentation of Design work.

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

SYLLABUS 1981

The course comprises one formal lecture per week, two principal design studies, a set of case histories of engineering design, background reading, and a final design study as a 5 day examination.

The lectures outline the course topics, and provide a guide to the meaning and relevance of the case materials as well as to the philosophy of the process of design.

Students experience the design process through their own application in fulfilling the needs expressed by the studies they choose to undertake. Tutorials are scheduled offering design discussion, and seminars outline background technology where necessary.

1. (a) The nature of creative work in engineering. Creative thinking. Obstacles and aids to creative insight. The role of knowledge. The influence of environments. The Personality of the Creator. The act of creation. A Theory of Physical Realisability. Feasibility Study. The Management of Creative people.

(b) Coursework. A creative design, or a feasibility study. 3 case histories of creative work by individuals, in the field of mechanical engineering. 2 assignments on these cases and associated readings.

The design process is here treated as though the designer operated in the fashion of a "black box". We know what goes in, and we see what comes out, but what happens inside the box? Potential research areas are identified.

The case material is presented in seminars and the understanding of this and the reading material is assessed by the grading of assignments.

The creative design study is chosen from a set of alternatives and occupies most of the first term time.

2. (a) Design as a systematic purposeful activity. The designer as a purposeful individual in a choice environment. Aids to the analysis of the initial needs specification. Development of knowledge and understanding of the state of the relevant art. Evolution of alternative courses of action. Marshalling, and display of evidence so that an informed decision becomes possible. The nature of the decisions of engineering design. Theory of decision taking. Optimisation Techniques. The optimum design of machines and machine elements. Optimum design of structures. Probabilistic approach to the design of elements and machines. Reliability Theory. Maintenance. Design planning and scheduling. Design Management.

(b) Coursework. The design of an item of mechanical plant to a specification. 2 case histories of mechanical design, showing both the individual design engineer at work, as well as a design team in industry.
A final assignment on these cases and associated readings.

The design process is here seen as a logical and systematic attempt to take informal decisions and proceed in a purposeful manner through all difficulties to define the optimum solution to the real design problem for the time being. The designer being considered as a "glassbox" so that we may appreciate precisely what he does and for what reasons. More potential research areas are indicated.

3. Some consequential topics:

Relevant background technology - notably gear design. Materials Selection. A systematic approach using a "materials optimiser". The analysis of machine element fractures in service. The influence of manufacturing processes on reliability. Visiting lecturers - as and when available.
The format of a designer's presentation and the nature and value of a designer's workbook.

4. Textbooks

Siddall "Analytical Decision Making in Engineering Design".

Johnson "The Optimum Design of Mechanical Elements".

French "Engineering Design".

Reading

Adams "Conceptual Blockbusting"

Starr "Product Design and Decision Theory"

Glegg "The Selection of......., The Science of........, and the Design of Design". A Triology.

Koestler "The Act of Creation".

Case Studies

Smyth, W.H. "Can soldering System" from Rossman "Industrial Creativity".

Jewkes "The Jet Engine" from "The Sources of Invention".

CEI. Case Study 75/03 "The EMI Scanner".

McKechnie "A Boomboat Drive and Steering System".

Booker "Design and Development of a Bellows Restraint Unit.

C.A. SATTERTHWAITE
Senior Lecturer in Mechanical Engineering

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

ASSIGNMENT PAPER NO. 1 - 1981

NOTES: The purpose of this paper is to help you appreciate the coursework material and in particular, the recommended readings. The value of so doing is not only relevant to your present undergraduate time, but also to your postgraduate experience as a professional engineer.

You should attempt to write answers to all the questions at some time during this year.

You are requested to submit written answers to Question 1 and TWO others by May 1.

1. Study the account of the invention by James Watt of the steam condensor. You can find this in one of Dickinson's books on Watt and in "Engineering Heritage", vol.1, p.57.
Describe the Newcomen engine and explain its thermal inefficiency.
Analyse Watt's own account of his insight in terms of the classical stages of creative thought due to Wallas.
Show that Watt's condensor remains essential to the thermal efficiency of a modern steam turbine generator. As an example, consider a steam plant operating with stop valve conditions 500°C/6 MPa at turbine inlet and exhausting at, say, 2 kPa. Show the significance of the heat drop with condensor as compared to that obtaining if the turbine exhausts to atmospheric pressure.

2. In the context of machine design write down definitions of 'complicated' and of 'simple'.
Gleg advises choice of the complicated rather than the simple alternative for a specific design. His justification is that precise complexity is preferable to the 'simplicity' of compromise.
Comment on this and then revise your definitions above to accept his philosophy.
Describe three examples of machine design bearing out this contention, and show explicitly how each does so.
How could the inevitable increased costs associated with such a choice be justified?

3. Glegg ('Design of Design', Chapter 3) maintains that excellence of design gives an authority which becomes uncritically accepted.
Explain in detail just how the Austin Seven car design set such a precedent in its field.
Can you provide at least one other design which is also uncritically accepted in its field, and explain the engineering design features which justify it?
Comment on 'uncritical acceptance' of excellence as a guiding rule for a designer.

4. The artistic merits of engineering design are interpreted by Glegg as the result of a sense of 'engineering style'. (See Chapter 4 'Design of Design').
Explain what Glegg means by 'style'. Refer to Chaddock and write out for comparison his interpretation of the artistic content of engineering design.
Does he too find a sense of style to be essential?
Can you illustrate engineering style by a specific example of design?

5. Prepare answers to the four preliminary 'creative' problems attached to this paper. Problem No. 2 is from von Fange 'Professional Creativity', Chapter 2, page 22. Problem No. 3 may also be found in Adams 'Conceptual Blockbusting', Chapter 1.

Write each answer on the relevant problem sheet. Describe also the thinking language you used. Was it verbal reasoning, mathematical logic, graphic logic or visual imagery? How many correct solutions exist to each problem? Which requires creative thought and why?

April 1981 C.A. Sattherwaite

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN 3 (MECHANICAL)

A "creative" problem

1. While a ship is floating in a canal lock, some deck cargo accidentally slides overboard and sinks to the bottom of the lock. If the gates remained closed during this time, what happened to the water level in the lock? Did it go up, down, or remain at a constant level?

(Buhl)

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DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN 3 (MECHANICAL)

A "creative" problem

2. A tank wagon is at rest on a railway siding. The tank is transversely divided into two equal compartments. The right-hand side is filled to a certain pressure with gas. If a valve separating the right from the left compartment is suddenly opened, determine whether the tank wagon would remain stationary or if it would move. And, if it moves, would it travel to the right or to the left?

(von Fange)

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DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN 3 (MECHANICAL)

Try this exercise in visualisation

3. One morning, exactly at sunrise, a Buddhist monk began to climb a tall mountain. The narrow path, not more than a foot or two wide, spiralled around the mountain to a glittering temple at the summit.

The monk ascended the path at varying rates of speed, stopping many times along the way to rest and to eat the dried fruit he carried with him. He reached the temple shortly before sunset. After several days of fasting and meditation he began his journey back along the same path, starting at sunrise and again walking at variable speeds with many pauses along the way. His average speed decending was, of course, greater than his average climbing speed.

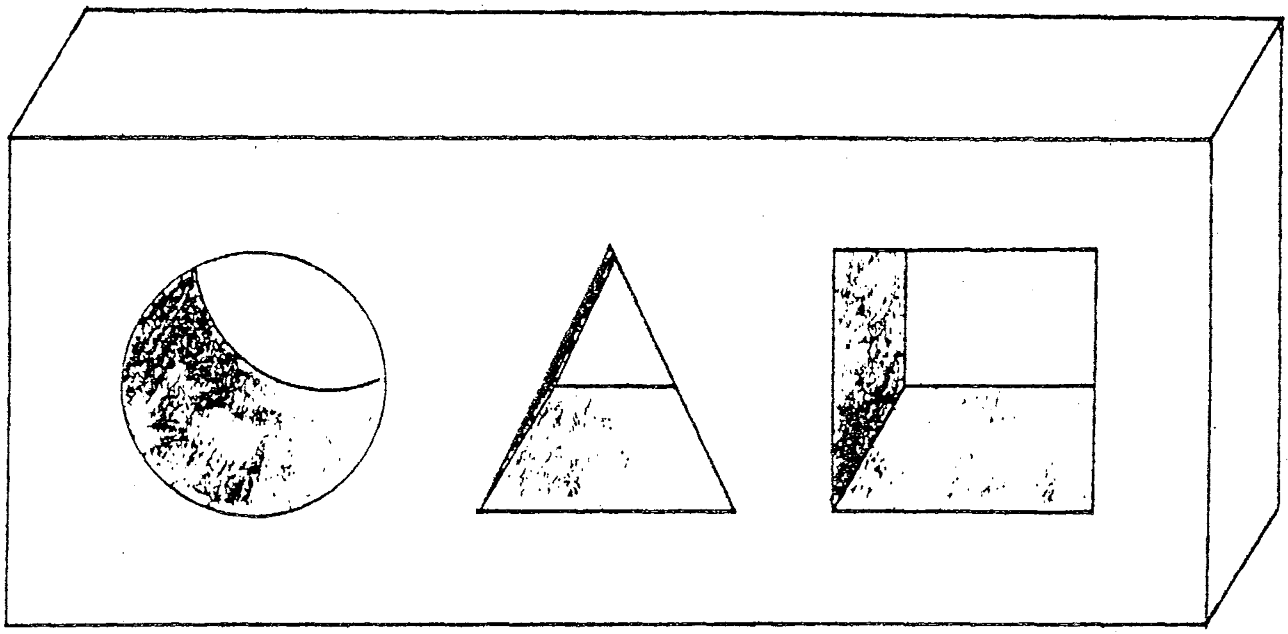
Prove that there is a spot along the path that the monk will occupy on both trips at precisely the same time of day.

(Koestler)

UNIVERSITY OF CANTERBURY

Department of Mechanical Engineering

DESIGN III (MECH)



The figure shows a solid block that has been pierced with circular, triangular and square holes. The diameter of the circle, the height and base of the triangle, and the sides of the square are all of the same dimension. The holes are pierced right through the block perpendicular to the plane face shown.

Visualise, and then draw, a single solid object that will pass all the way through each hole and, in so doing, entirely block the passage of light. Describe a sequence of operations for machining this object from a standard piece of material.

(McKIM)

C.A. Satterthwaite,
Senior Lecturer.

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH)

ASSIGNMENT PAPER NO. 2. 1979

NOTE: This paper has the same purpose as No. 1. You are requested to undertake to answer all the questions for your own benefit, and to submit a written answer to TWO of the questions by June 8th.

1. Is the purely rational engineering design possible? For example, evaluate the 'floor covering machine' described by Glegg as a rational design.

   Explain the logic of the I.C. engine design-development process described by Chaddock in Part 4 of his paper. Can this be recognised as the same intellectual process as was used to develop the can-soldering system design?

   Explore the differences, and identify any 'insights' involved, in any, or all 3 cases.

2. Both Whittle and Hounsfield were employed by large organisations when they carried out their creative work. How did the working environment and the management policy frustrate, and also encourage, their labours?

   From the evidence available in the case histories, deduce the outstanding personal characteristics of each designer.

   Does Glegg present a similar personality? Describe him as an innovator and compare his professional environment to that of the others.

NOTE: In considering this question (and No. 3 below) you can refer to Procs. I.Mech.E., 1945, 152, 419, Whittle "The Early History of the Whittle Jet Propulsion Gas Turbine"; also, Whittle, "Jet, the Story of a Pioneer", 1953. These readings will extend the Jet engine case history considerably.

3. List the technical problems Whittle had to overcome to ensure his first experimental engine would work. (Use a diagram of the standard constant pressure cycle to illustrate this).

   Describe the perceptual block discovered by Whittle when he compared his gas turbine blade designs to those conventional to the steam turbine manufacturers with whom he was working.

   Why was the established aero engine industry unlikely to be the innovator in the field of gas turbine design, and jet propulsion, for aircraft?

4. Read von Fange, Appendix 1, p. 223 and write a precis.

   Note that Glegg and Kettering have a lot in common in their approach to innovation. Try to isolate and write down such common features. Produce evidence from the text to show Kettering could not be a professional engineer!

5. How did Hounsfield develop the 'insight' which became the EMI scanner? Compare to the insight by Watt which became the steam condensor. From the case history, explain how confidence was built up in the insight so as to present a convincing proof of its value to management. Isolate the critical steps, in the process.

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DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECHANICAL)

ASSIGNMENT PAPER No.2, 1984

NOTE:

This paper has the same purpose as No.1. You are requested to undertake to answer all the questions for your own benefit, and to submit a written answer to TWO of the questions by 3 August.

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1. Both Whittle and Hounsfield were employed by large organisations when they carried out their creative work. How did the working environment and the management policy frustrate, and also encourage, their labours?

   From the evidence available in the case histories, deduce the outstanding personal characteristics of each designer.

   Does Glegg present a similar personality? Describe him as an innovator and compare his professional environment to that of the others.

   NOTE: In considering this question (and No.2 below) you can refer to Procs. I. Mech.E., 1945, 152, 419 Whittle "The Early History of the Whittle Jet Propulsion Gas Turbine"; also, Whittle, "Jet, the Story of a pioneer", 1953. These readings will extend the Jet engine case history considerably.

2. List and describe the technical problems Whittle had to overcome to ensure his first experimental engine would work. (Use a diagram of the standard constant pressure cycle to illustrate this.)

   Describe the perceptual block discovered by Whittle when he compared his gas turbine blade designs to those conventional to the steam turbine manufacturers with whom he was working.

   Why was the established aero engine industry unlikely to be the innovator in the field of gas turbine design, and jet propulsion, for aircraft?

3. How did Hounsfield develop the 'insight' which became the EMI scanner? Compare to the insight by Watt which became the steam condensor. From the case history, explain how confidence was built up in the insight so as to present a convincing proof of its value to management. Isolate the critical steps, in the process.

4. With reference to the "Ducts and Valves" case study. Why was the proposal to use co-axial ducts for the AGR reactor coolant system so significant?

   With reference to the performance specification for the system, explain the technical advantages of such an arrangement and list the consequential sub-problems its adoption entailed.

   The alternative valve arrangements considered by the design team utilise three fundamental valve types. Explain the operation of each type of valve. Criticise the choice of a butterfly valve and show how the Blakeborough design was successively refined to justify it. (Refer to Marples "The Decisions of Engineering Design" held 'On Reserve' in our Library.)

5. APT Power Car Sole Bar. Explain the criteria governing the final material choice for the power car sole bar. Summarise the functional requirements for the sole bar design, and the space limitations. List the criteria against which the design proposals were judged, and evaluate each one. Why was the 'baseline design' so attractive and how does the production version constitute a development?

C.A.Satterthwaite
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UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3(M).

ASSIGNMENT PAPER No. 3, 1979

Please submit a written answer to ONE of the questions below, by Friday, 12 October.

1. Describe the design-development process of the "Boomboat Drive" in terms of courses of action, outcomes (i.e. problems arising), and decisions taken. Use a 'decision tree' layout where possible. Hence identify insights. Criticise Ray Sanders as a designer and show where he could have adopted more systematic techniques, (both of analysis and synthesis), in formulating problems, searching for knowledge and understanding, and developing solutions.

2. Consider the design-development leading to the frustro-conical proposal for the ductwork restraint units for Transfynydd Nuclear Power Station. What was the 'state of the art' as far as RWG designers knew it?

Summarise the design situation facing RWG engineers, in terms of design criteria (duty), functional restraints, and regional constraints.

Describe the insight which led to the frustro-conical proposal. If - as a junior design engineer - you had had this inspiration, how would you have presented it to the project engineer in charge of the design team?

On the face of it, this solution to the problem of providing flexible ductwork seems to be very complex and expensive. Is this a case of "precise complexity" being preferable to the compromise of simplicity - to use Glegg's terms? How precise is the operation of this restraint unit?

C.A. SATTERTHWAITE

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.) 1981

DESIGN STUDIES - FIRST TERM

Select ONE only from this list by March 16th. Your proposals for the design are required by May 1st.

1.	A locking system for a skyline carriage used in logging operations (LIRA) -	R.D. Gordon
2.	A fold-away log bolster assembly for log trucks (LIRA).	R.D. Gordon
3.	Hygenic Rotary Airlock Valve. To meter a product feed into a conveying pipe line.	W.P. Studd (Windsor Eng. Ltd.)
4.	A one-man alluvial gold dredge.	E.P. Giddens.
5.	A refuse system design.	G.A. Britton.
6.	A supermarket design.	G.A. Britton.
7.	An analogue model to solve Plant Location Design problems.	G.A. Britton.
8.	A Propeller Shaping Machine.	K. Whybrew.
9.	A Solar Irrigation Pump.	C.A.Satterthwaite.
10.	An Energy Absorbing Car Bumper.	C.A. Satterthwaite.
11.	A system to recover the metal of cans.	C.A. Satterthwaite.
12.	A new ski-binding to replace the heavy and rigid boots with a more effective, comfortable and practical device.	C.A. Satterthwaite.

NOTES

1. Not more than 5 students per study.
2. Open a designer's 'workbook'.
3. Attend the weekly tutorial.
4. Use the Mechanical Dept. drawing office and watch the notice board.

C.A. SATTERTHWAITE
Senior Lecturer in Mechanical Engineering

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.) - 1983

DESIGN STUDIES - 1st TERM

Select ONE only from this list by March 10th. Your proposal for the design is required by April 29th.

1. Cable Tension Monitor C.A.S.

2. Set of tools for the DIY market to cut out and flatten can material, and then to bend and press into useful products. C.A.S.

3. Design, make and proof test a structure. C.A.S.

4. A propellable Standing Frame for the disabled. A.D.

5. A retractable Attic Step-ladder. A.B.

6. Overspeed Protection for turbine alternator drive. P.C.

7. Radio Tower with horizontal Yagi Antenna. A.J.G.P.

8. Rainwater collector with purity selector. A.T.

9. Equipment to demonstrate the Momentum Equation. G.J.P.

10. Design of 360° hinge and manufacture. L.A.E. et. al.

Notes:

1. The student body will be distributed as evenly as possible over these choices.
2. Open a designer's 'workbook'.
3. Attend the weekly tutorial.
4. Use the Mech. Dept. Design Office and watch the noticeboard.

C.A.Satterthwaite

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DEPARTMENT OF MECHANICAL ENGINEERING

Engineering Design 3 (Mech.) - 1984

Design Studies - 1st Term

Select ONE only from this list by 8 March. Your proposal for the design is required by April 26.

Study No.	Description	Customer
1	Tree de-limbing training bench	Logging Industry Research Association
2	Skidder Operators Restraining Device	"
3	Skyline Logging to an Offshore Barge	"
4	Mobile crane design-development	C.W.F. Hamilton
5	Mobile Tower for wind profile measurements - re-design	Dept. of Mech.Eng. (Mr Harris)
6	Design-make-proof test a structure	C.A.S.
7	Wheelchair re-design	Mr Tarrant and C.A.S.
8	Hurdle Design, etc.	Dr A.S. Tucker
9	Overspeed protection system for hydro-electric generating plant	Peter Giddens, Civil Engineering Dept.
10	Hydrostat re-design	" "

Note: 1. Open a designer's 'workbook'.

2. Attend the tutorials.

3. Use the Mech.Eng. Dept. design office.

4. Scan the noticeboard regularly.

C.A. Satterthwaite
Senior Lecturer in Mechanical Engineering

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

Design Study for Second Term

Select ONE only by June 1st.

1. A special purpose winch is required for use in Alpine rescue. Existing equipment exhibits many defects, and a fresh specification is being written to develop a new generation of rescue winch, that is more reliable and versatile.
(5) A.S.

2. A radio transmitter tower design. The tower is required to be transportable, easily erected and dismantled and to include accurate and reliable means to orient the aerial array.
(5) A.P.

3. A hot glass handling system. This is required by Crown Crystal Glass at their Hornby factory. The system to be fully automatic. To quench and accumulate glass for conveying to storage bins.
(6) B.R./C.A.S.

4. The design of brakes. You are required to survey the design of mechanical brakes, considering the principles involved, the history of the development of specific types, and the fields of application. Hence to develop guides to the design and selection of brakes for optimum performance.
C.A.S.

5. The design of a machine system for the assembly of small mechanisms.
(6) K.W.

6. A pressure vessel design. A polymerisation reactor vessel for a production plant to be associated with the Maui Natural Gas Distribution Centre. C.A.S.

7. A high speed gearbox design. To drive a gas turbine rotor test cell. Input from a 2000 H.P. 60 Hz 1800 RPM motor. To drive rotors on test at speeds up to 55,000 RPM.
C.A.S.

8. A speed reducing gearbox for general application to the drive of conveyors and pulp and paper mills. To deliver 100 H.P. at 50 RPM continuously. Overall speed ratio 960 to 50 RPM with a tolerance of ± 1 RPM. To conform to the general design of parallel shaft gear boxes for industrial use.
C.A.S.

9. A management control system design. Refer to the 1978 annual examination paper ENME 411 - question No. 4.
H.McC.

10. Design of Goods Lift Inclinator. To design a three rail track goods lift with two cars passing in a bay at the mid-point allowing a balanced system to be used.
(8) D.C.S.

NOTE: Completion date is August 10th.

C.A. SATTERTHWAITE
Senior Lecturer in Mechanical Engineering

<u>UNIVERSITY OF CANTERBURY</u>

<u>DEPARTMENT OF MECHANICAL ENGINEERING</u>

<u>ENGINEERING DESIGN 3 (MECH.)</u>

<u>Design Study for Second Term</u>

Select <u>ONE</u> only by June 1st.

1. A special purpose winch is required for use in Alpine rescue. Existing equipment exhibits many defects, and a fresh specification is being written to develop a new generation of rescue winch, that is more reliable and versatile.
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(8) D.C.S.

<u>NOTE</u>: Completion date is August 10th.

C.A. SATTERTHWAITE
Senior Lecturer in Mechanical Engineering

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DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3

Design Study No. 2 - 1983

YOUR COMPLETED DESIGN IS REQUIRED BY 12 *AUGUST* 1983.

WESTLAND PORT DEVELOPMENT LTD

Provision of general purpose wharf crane for new port facilities on West Coast of South Island of New Zealand.

Type: Mobile, tracked, self-propelled, level luffing crane with portal type sub-structure. Capable of conversion to use of a grab, and handling of containers.

Design of Hoisting System

Capacity: General cargo 5 tonne max. at 42 m/min.

(Heavy lift capability 18 tonne max. at 21 m/min.)

Estimated duty during 8 hour shift - 30 lifts/hour, 1000 hours/year. Average load 1/3 max.

Max lift = 41 metres.

Typical duty cycle:

Hoisting	36 secs.	loaded
Luffing & Slewing	8 secs	"
Lowering	10 secs	"
Pause	5 secs	"
Hoisting	10 secs	Empty
Luffing & slewing	8 secs	"
Lowering	20 secs	Free barrel
Pause to load.		

Power: All electric using DC Series/Compound motor. Max. motor speed is 480 rpm.

STUDY 1. Outline a suitable hoisting system.

2. Design the necessary gearbox for the system, complete.

REFERENCES: Use Atherton "Hoisting Machinery" and Broughton "Electric Cranes".

Consult the Library, and note any Standards and Regulations governing the design and use of cranes in New Zealand.

C.A. Satterthwaite
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UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH)

DESIGN STUDY No. 2 - 1983

Your completed design is required by 12 August 1983.

PLANT FOR PROOF TESTING OF GAS TURBINE ROTORS

Outline specification for the high speed gearbox:

Input 2000 H.P. 50 Hz motor, 1500 R.P.M. synchronous speed, driving through an eddy current coupling.

Duty To transmit 220 lb. ft. torque at speeds up to a maximum of 45,000 R.P.M. corresponding to 1400 R.P.M. at input. By simple changes of gear ratio, speeds between 20,000 and 55,000 R.P.M. to be obtained for values of torque of 525 lb. ft. and 175 lb. ft. respectively.

Loading Pattern. The test cell does not run continuously. Time to assemble the rotor on test in the cell is appreciable. Probably at most 2 test runs per day, of 3 hours each at 45,000 R.P.M. for 5 days per week. Alternate weeks may include similar runs at 55,000 R.P.M. Compressor test runs at 20,000 R.P.M. of the same frequency will be made.

Production. An initial order for two only gear boxes to this specification has been placed.

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DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

DESIGN STUDY NO.2 - 1981

YOUR COMPLETED DESIGN IS REQUIRED BY 14 AUGUST 1981

Conveying System for the Inky-Black mine, Westland.

Your Company has tendered for the design, construction and commissioning of a coal-conveying system to deliver the output of the Inky-Black mine to the new port facilities at Westland for export to Japan.

Your Chief Engineer has decided to use belt conveyors for the system, and you are a member of the conveyor drives design team.

Investigation by your Project Engineer shows that there is not available a suitable commercial gear box for the drives so it is decided to carry out a special design to suit the conveyor system; for manufacture in Christchurch.

Specification

A speed-reducing gear box for a conveyor drive. To deliver 100 H.P. at 55 r.p.m. continuous rating. Ratio 980 to 55 r.p.m. with a tolerance of ±1 r.p.m. To conform to the general design of industrial parallel shaft gearboxes. A batch of five only boxes will be made for the conveying system. The gears will be ordered out from a specialist manufacturer. The emphasis will be placed on reliable operation and compact design.

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DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

DESIGN STUDY NO. 2 - 1980

Your completed design is required by 22 August 1980.

A 600 SHP GAS TURBINE FOR MARINE USE

This outline specification is for a prototype gas turbine utilising the gas from a free piston type generator. It is an attempt to provide a more compact power unit for a new generation of New Zealand deep water fishing vessels. It would be recommended for use only where adequate shore based scheduled replacement maintenance system facilities could be provided.

Gas Input From a free piston gas generator at 450 to 500°C and 50 lb/sq. in. Mass flow to suit turbine capacity.

Turbine Duty. To provide an output of 600 SHP at an output shaft speed of about 2000 RPM.

Provision for appropriate heat exchangers in the exhaust system to economise on the fuel consumption should be considered.

Production. Keep the turbine design to a single stage. Probably a batch of 50 units would be made after proving the prototype.

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DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

DESIGN STUDY NO.2 - 1984

Your completed design is required by ~~7~~ 14 September 1984.

Steam Turbine-Generator set for Sugar Processing Plant.

Prepare a design for the following plant to supply 450 kW 50 Hz electrical power and process steam at 11 Bar.

Inlet steam at Stop Valve	-	28 Bar/425°C
Exhaust Pressure	-	11 Bar
RPM	-	To correspond to optimum turbine efficiency - approx. 6000.

Generator 1500 RPM, 50 Hz, 450 kW.

Coupling gear box to be epicyclic.

A compact set mounted on a common foundation is required.

C Satterthwaite

C.A. Satterthwaite
Senior Lecturer in Mechanical Engineering

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DEPARTMENT OF MECHANICAL ENGINEERING

ENGINEERING DESIGN 3 (MECH.)

DESIGN STUDY No. 2 - 1984

Your Completed Design is required by ~~7~~ 14 September 1984

DESIGN OF A CONSTANT VOLUME BOMB

A constant volume vessel is required so that individual explosions of gas-air mixtures can be studied.

The volume contained within this bomb would approximate to the swept volume of a cylinder of a medium sized car engine.

The bomb must be able to carry out the following functions:

1. Allow mixture entry.

2. Allow mixture exit.

3. Provide a spark for ignition.

4. Provide a means of inducing turbulence.

5. Allow for pressure measurements.

6. Provide a spare part for instrumentation, i.e. thermocouples, turbulence measurements.

Details of ancilliary equipment necessary to enable the above functions to be carried out must be included in the design.

Dr R.K. GREEN

SOME NOTES ON "TEACHING" DESIGN

1. Lectures alone can do very little to teach design. However the lecture series provides a guide to the current theories, accomplishments, techniques and location of reference material.

2. Personal involvement in the design process under tutorial guidance, and moral support, is the method by which 'design' is taught. To this end, the studies set should impel the student into this experience.

3. A tutor does not 'teach' design in the manner in which a science or technology is taught. Classical scientific method analyses well defined and idealised situations, mathematically and/or experimentally. Courses of study recapitulate well-known analyses with well-known results. Research applies the same method to new situations secure in the knowledge that a result is inevitable.

4. Design activity cannot be said to be a science in that classical sense, although it makes use of sciences and scientific method. Furthermore the motivation to design provides the need for further scientific research as design activity proceeds. Engineering design is rather the art of putting ingenuity to worthwhile uses, in a systematic way.

5. Design topics proposed by tutors should represent needs, presently unsatisfied, which offer interesting possibilities for the application of engineering and which appeal to the imagination, and could be of value should practicable solutions be found. Thus the 'worthwhile uses' of ingenuity may be extended.

6. The design process begins when the challenge to satisfy the expressed need is taken up. Initial motivation must be high since it is not long before the alternative strategies available turn up their peculiar problems. It is the handling of these consequential difficulties that provides most of the material of tutorial discussion.

7. Regular tutorials are to be preferred. The design group should designate some definite material as the 'goal' for each session. As far as is possible each tutorial should represent 'a systematic interview' in which the tutor finds out, at least, what, if anything, the designers have done!

8. Ideally the tutor should not lead the group, nor should he set the goals. He provides, best of all, experienced support passing his judgements on work done and proposed, more by asking the proper questions than by direct answers to cries for help.

9. The philosophy developed by a designer is more a certain personal attitude of mind towards design situations than any unique expertise of 'design'. It is suggested that application of the many techniques and thoughtful use of the various systematic aids to the design process will, after a time, generate for each designer a philosophy relevant to his own talents.

10. It is necessary for the tutor to remember that the student is to be the designer and not himself. Even if the device or system to be designed never 'gets off the ground', this is of little consequence in itself, providing always that the student experiences the agonies of the design process.

11. The responsibility of a design tutor is therefore to try to see the design process in evidence on the student's part. His tutorial schemes should have only this objective. The experience is quite different from supervision of research work and is often far more rewarding to all concerned.

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UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN 3 (MECH).

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SOME NOTES ON THE PRESENTATION OF DESIGN WORK

- SECOND TERM -

Hand in:
1. Your rough work entire - preferably in book form.
2. Report on your design proposal.
3. Drawings relevant to (2).

Design Report: This is meant to be an accompaniment for your drawings. It is NOT to be a write-up of all your rough work. It may comprise the following:

Section 1 - A description of the proposed plant.
" 2 - A concise specification of the items of plant designed.
" 3 - Materials chosen. Specifications. Recommended treatments.
" 4 - Any special notes on construction, e.g. weld procedures, joint tightening and fits.
" 5 - Testing procedures before release to service. Performance data.
" 6 - Lubrication recommendations. Cooling.
" 7 - Recommended accessories, e.g. couplings and instrumentation.

Drawings: Should comprise the following:

No. 1 - A general arrangement to show assembly, overall sizes and to include a complete Parts List.

No. 2 - Major parts, e.g., pinions and gears with a cutting table with checking data.

No. 3 - Minor parts, e.g. shafts, keys, locating devices for bearings or details of joints.

No. 4 - Gear box itself with bolts and dowels.

No. 5 - Gear box accessories, e.g. couplings, lubrication system, etc.

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